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ABSTRACT

These proceedings include abstracts and/or complete papers on topics and research focusing on student misconceptions (ideas at variance with accepted views) in science and mathematics. Abstracts and papers are arranged according to nine general areas emphasized: (1) theoretical and philosophical perspectives; (2) instructional issues; (3) research methodological issues; (4) historical and epistemological perspectives; (5) elementary school science; (6) physics; (7) biology; (8) chemistry; and (9) mathematics. Selected topics addressed or areas investigated include implications of research on misconceptions for teaching, misconceptions and conceptual change, interpreting evidence about misconceptions, the microcomputer in cognitive development research, a 12-year study of conceptual development using concept mapping as an evaluation tool, students' misconceptions in geometric problem solving and genetics, using conceptual change to understand problems students have in learning science, and students' alternative conceptions of mechanics. Issues raised in plenary sessions and a list of research needs are among the areas considered in the introduction to the proceedings. These needs include studies of conceptual change, studies to identify consistent or robust misconceptions, studies focused on theoretical issues, studies on sources of misconceptions, and studies on teacher education with awareness of misconceptions. (JN)

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Proceedings Of The

International Seminar

MISCONCEPTIONS IN SCIENCE AND MATHEMATICS

JUNE 20-22, 1983

CORNELL UNIVERSITY, ITHACA, NY, USA

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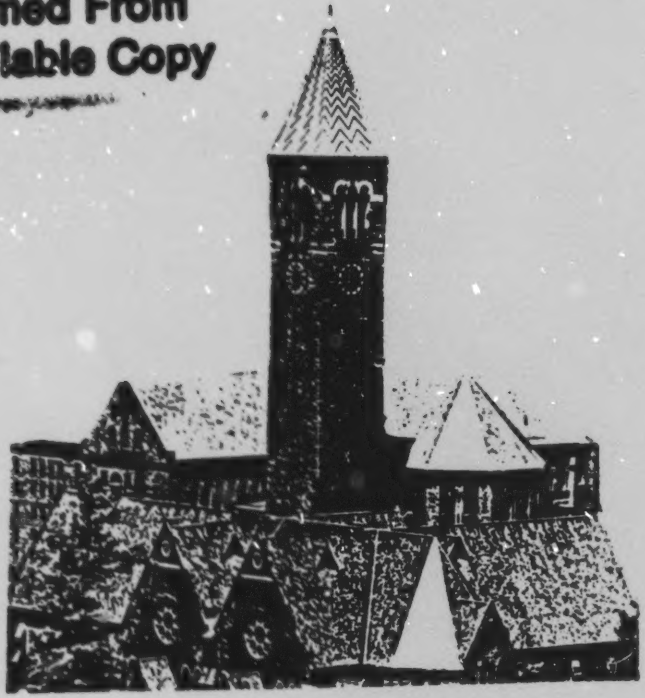

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Overview of the Seminar

Joseph D. Novak

The idea of this seminar originated over lunch in October, 1982 when Hugh Helm and I discussed ways to make Helm's sabbatical year at Cornell a profitable one. Given our common interest in student misconceptions (alternate frameworks, or whatever we choose to call these regularities) and the importance that research in this area has achieved in recent years, it seemed to be a good idea to invite scholars we knew to a two or three day seminar on the Cornell Campus. With very limited financial support in prospect and a tight time-table, we proceeded to send letters and informal notices to several hundred scholars. Some of our colleagues joined us in planning for the seminar. We were overwhelmed by the strong positive response, and most pleased by the number and quality of papers submitted. More than 118 persons registered for the Conference and fifty-five papers were presented, most of which are included here. We apologize to those researchers who were missed in our limited promotional efforts.

Our primary purpose was to encourage dialogue between scholars, and thus most papers were scheduled for 45 to 60 minutes with the intent that about half of this time would be used for discussion. Afternoon general discussion sessions were also scheduled for each of the three days to discuss "issues of the day" suggested by participants. Abstracts of all papers were distributed prior to the seminar to permit some time for selecting which of three or four parallel sessions to attend. A wine and cheese reception on Sunday evening and buffet dinner on Monday evening helped participants become acquainted and afforded additional opportunities for informal discussion. Participants response was gratifyingly positive with the major complaint being that some speakers talked too long - not an uncommon problem with professors. One-on-one and small group discussions were abundant, many running on into the early morning hours.

By the end of the first day of meetings, several issues emerged for discussion. As might be expected, one of the issues was what name to use for these things we were concerned with - everyone knows that "misconceptions" carried with it some connotations that are not appropriate. We agreed to defer discussion on this, although the issue remained with us throughout the seminar. More on this later.

I will not attempt to summarize the papers presented here. Each of the abstracts of the papers is included as well as most of the papers. Suffice it to say that all of us were impressed with the extraordinary commonality of interests and the overriding recognition that the solution to the problems of numerous student misconceptions would not be an easy one. We also recognized why many of the science and math curriculum projects of the 1950's and 1960's failed to achieve their hoped for promise - most of them failed to recognize the profound influence of students prior conceptions (alternative frameworks, etc.) and their resistance to modification in "conventional" instructional.

Piagetian studies have been immensely popular in science education and occasionally the role of Piagetian research emerged in the discussion. As Sidney Strauss observed, Piagetian studies are captivating in the research setting but of little value in classroom instruction. What the studies of misconceptions has shown is not that students lack competence in "logical operations" but rather the obstreperous influence prior conceptual frameworks have in shaping the meaning of new learning. No one stepped forward to advocate the thesis of Shayer and Adey (1981) that Piagetian theory could serve as the basis for a science of science education. There was support expressed for the idea that "discovery learning" may lead to elaboration of misconceptions, as recently argued by Driver (1983) in her excellent book.

Tuning again to the three plenary afternoon sessions, five "issues" were raised in the first Monday session. The five issues identified were:

1. To what extent are misconceptions language difficulties (i.e., a failure of teacher-student or interviewer-subject to share the meaning of the question(s) involved?

2. What is the perceived parallel between student misconceptions and the recorded history of science? Is it real and if so, where is the explanatory theory?

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3. Could we develop a dictionary of terms for these "things," with each person indicating their name and reasons for this choice?

4. What do we know about changing the views of college professors regarding the value of research in science education (i.e., their attitude that if you know the subject well, you can teach it.)?

5. To what extent can knowledge of misconceptions guide instruction?

The group decided to pursue the last question first, and very lively discussion followed. Incidentally, these plenary sessions were recorded on half-inch video cassette tap (JVC equipment) and can be made available to interested parties for the cost of duplication and mailing. Hugh Helm superbly moderated all of the discussions and Jane Heinze served as recorded on Wednesday.

Several issues were identified. Teachers are usually not aware of student misconceptions and hence proceed blithely to discuss new topics as though students were tabula rasa "tape recorders." All of the research evidence shows that this is not the case! Schuster and others noted that textbooks are often at fault, since they contain information that is misleading or wrong. A number of participants indicated that knowledge of student misconceptions can help teachers at least to recognize the problems they confront -- and at least to be tolerant of student's prior "frameworks." One participant noted that she saw nothing wrong with some student's physics conceptions and emphasized that teacher's, too, hold misconceptions. Incidentally few teachers have the ego security of the latter participant to admit that their cognitive organization of concepts may be faculty. It was observed that students, especially college students, are very clever at hiding their misconceptions by remaining reticent and "playing the game" which may include verbatim responses to questions or "algorithmic solutions" to standarad text-type problems. It was further noted by Joan Solomon that there is no substantive evidence that student awareness of alternate conceptions leads them to "correct" their own cognitive frameworks.

Plenary Session One ended with Questions bristling in the group, but it was necessary to adjourn to progress to the evening buffet dinner. Problems and issues, as well as light conversation, were encouraged by the ambiance of the "Old Red Barn" setting, wine, dinner and beer.

Plenary Session Two added the issue, "Can metalearning and metaknowledge instruction help students to overcome their misconceptions?" Before launching into this issue, Herb Lin's concern with misconceptions "university types" have about science education research was aired. As Herb pointed out, this is a minor issue for those of us who have tenure, but how about the Herb Lin types! There was an acknowledgement that much of what paraded under the flag of "educational research" was valueless and hence we had to deal with a genuine image problem. Others expressed the view that if we do worthwhile research, it will capture the interests of our colleagues (and "misconceptions" research was cited as an example). The general concensus was that it is hard to straighten out the educational world, but if we keep plugging away,our work and our cause can and will be recognized and valued. A grand dream? I think not.

The issue of terminology came up again. Gowin cited Joseph Schwab's observation that terms derive their meaning for the context of the inquiry. This is consonant with Kuhn's ideas of paradigms influencing research methodologies and Lakatos' ideas about the nature of evolving research programs. Fisher's review of the literature on misconceptions showed that the work was characterized by three ideas: (1) "misconceptions" are ideas at variance with accepted views, (2) many students hold the same "misconceptions", and (3) misconceptions" are obstinately resistant to change. The dialogues and tapes of this session added confirmation to Fisher's conclusions.

There was also the idea expressed that the study of "misconceptions" can inform on the workings of the mind in a way analogous to the way that pathologist help to inform us or the nature of normal physiology. I believe there is merit in this view.

Finally, the discussion turned to the issue of metalearning and metaknowledge instruction. It was clear that many participants had not considered this issue substantively in their previous work, as little was done beyond some further explication of the idea, especially for participants who missed the session by Gowin and myself.

Our final session on Wednesday returned again to the issue of "why isn't science education a valued enterprise, with an affirmation once again that if we do (continue to do?) worthwhile research and apply it to practice, we will be "appreciated."

Sara Ulerich suggested several concerns including the need to identify "consistant and robust" student misconceptions. She also raised the issue of classification of student's thought (i.e., Aristotelian) and the broader view of misconception change -- "conceptual change." Reinders Duit, Gaalen Erickson, John Schwartz, Joseph Nussbaum, Ed Smith, Jean Lythcott, Kathy Fisher, George Posner, Bob Gowin, Jim Wandersee and others commented on the issue. The consensus was (I believe) that we are dealing with a broad set of issues that confound methods of inquiry and evaluation with factual data, as well as with varying theoretical perspectives. Overwhelmingly, the group seemed to be saying that we are dealing with a complex, multifaceted problem that has no easy "quick fixes." Parenthetically, I sense the feeling that the growing world-wide concern for the quality of science and math education could lead to politically enticing "quick fixes" that could have long-term deleterious consequences for our field.

The discussion turned to ideas for a "research agenda," although there was some debate as to the value of identifying research questions in that any listing would be incomplete and/or might straitjacket future research in this area. Nevertheless, there was sufficient support for sharing ideas on researchable topics that a number were identified including the following:

1. Studies of conceptual change; how it occurs "naturally"; how it occurs (or fails to occur) with planned instruction.

2. How/why do student conceptions influence (shape) their experience in instruction.

3. Continued studies to identify consistent or robust misconceptions.

4. Studies of "modes of thinking." e.g., "Aristolelian," "anthropomorphic" and relationships to misconceptions.

5. Studies on methodological issues, e.g., interview techniques, concept mapping, test validity, instructional variables.

6. Studies on particular populations, e.g., minority groups, adult learners, ethnic or cultural differences.

7. Studies focused on theoretical issues.

8. Studies of governance issues, or issues related to the social matrix of teaching/learning.

9. Possible value of history of science to understand misconceptions.

10. Studies on sources of misconceptions.

11. Studies on influence of student awareness (metaknowledge, metalearning).

12. Studies on the design of alternative instruction materials taking into account misconceptions.

13. Studies on teacher education with awareness of misconceptions.

Again, let me caution that these are only some good researchable topics; it would be faulty to limit "membership" to the misconceptions research club only to people whose studies dealt with one of the above.

In summary, the "sense of the meetings" seemed to be that we were dealing with a topic of profound importance and problems which have no easy solutions. The general counsel appeared to be, "be wary of prophets who have snappy solutions."

Given the good counsel of our colleagues, how do some of us at Cornell University have the temerity (audaciousness?) to suggest that there may be a way out of the "misconceptions" morass. How can we propose that "metalearning and metaknowledge" instruction may be a potential long-term solution. I would respond to this with two major points. First, until the 1960's, we did not have an adequate theory of learning that could guide educational practices in classrooms and that addressed the key issues of cognitive development. We believe that Ausubel's assimulation theory of cognitive learning, combined with new instructional strategies based on this theory (Novak and Gowin, in press) can be a psychological foundation for qualitatively improved instruction. Second, advances in epistemology (or our understanding of the nature of knowledge and knowledge production) are highly complementary to the latter psychology of learning in that both stress the evolutionary (or ontogenic) development of hierarchically organized conceptual frameworks. Third, we believe that the development of pedagogical and instructional strategies such as "concept mapping" and "Vee mapping" provide a means to help students "learn how to learn" and to understand the nature of knowledge production. We believe these two instructional strategies are only the first of a potentially significant number of new pedagogial innovations that are "theory driven."

For thirty years, Bob Gowin and I have strived to construct some comprehensive framework of ideas and principles to guide educational practices. My (1977) A Theory of Education and Gowin's (1981) Educating are the first and only efforts we are aware of that attempts to construct a comprehensive theory of education. For our research group, these complementary theories have been highly productive and underpin all of our current research studies, including the work of more than forty graduate students and visiting professors. We believe that "theory driven" research can help to advance studies on student misconceptions. New strategies for helping students "learn how to learn" (Novak and Gowin, in press) derive from these theories.

From the theoretical context of education we have been developing, we might follow up Jean Lythcott's suggestion of using a "meaningless" or Greek or Latin label for the things we now refer to as misconceptions, alternative frameworks, pre-instructional ideas, etc. I would suggest the name LIPH, an acronym for "Limited or Inappropriate Propositional Hierarachies." We see propostions (two or more concepts linked together) as the "molecules" of meaning. The meaning of a concept derives largely from the hierarchical framework of propositions in which the concept is embedded, and hence meanings develop over a life span and become increasingly resistant to substantive alteration. Concept maps are a method to depict concept meanings as they portray hierarchies of propositional structures. And here is the rub, a label such as LIPH is loaded with "context dependent" ideas including the idea that we assess student understanding with something like concept maps and knowledge Vees, the former showing "misconceptions" and the latter showing faculty connections with objects or events in the world or records of these or claims we make about the records. Solomon was especially concerned with a definition that might imply too much about the nature of misconceptions.

The consensus of the seminar group was that it is too early in the history of our research programs to label explicitly these things most of us call "misconceptions" and to imply what may be their nature original and resistance to change. This is sage advice, and so we conclude this overview by saying "keep on open mind."

This first international seminar on student misconceptions should not be the last. We would be willing to host another seminar program at Cornell University in 1985 and we invite the readers' comments and suggestions for a future seminar. We would be pleased to share our computerized roster of names and addresses, and other information, with scholars interested in communications with the "invisible college" of researchers committed to understanding how humans acquire and modify meanings and how they seek to integrate thoughts, feelings, and actions.

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ABSTRACTS OF PAPERS PRESENTED

GROUP ACCORDING TO PRIMARY EMPHASIS OF PAPERS

I. THEORETICAL AND PHILOSOPHICAL PERSPECTIVES

IMPLICATIONS OF THE RESEARCH ON MISCONCEPTIONS FOR TEACHING

Jere Confrey
Mount Holyoke College

The research in mathematics education has documented repeatedly that students perform poorly on non-routine problems, that students' errors are reasoned and not capricious, that misconceptions on particular concepts are widely held, that students rely heavily on memorization and have weak strategies for approaching mathematical ideas. As a result, students hold conceptions of mathematics and mathematics learning which discourage conceptual development and the strengthening of mathematical processes. If such profound and convincing educational research is to become helpful and relevant to the classroom teacher, we must begin to develop some demonstration projects which are informed by these research findings and to seek to overcome the situation. The SummerMath program is a six-week program for young women in high school which is devoted to improving mathematical understanding for students for whom mathematics is a hurdle. In this presentation, I will suggest that a constructivist approach provides an appropriate theory through which to interpret these research findings, and I will discuss what I mean by constructivism. Finally, I will talk specifically about the implications of such a theory for curriculum writing and for instruction in mathematics.

THE INFLUENCE OF MODEL-INSTRUCTION ON "CONCEPTION- AND MISCONCEPTION-LEARNING" IN BIOLOGY AND PHYSICS

Wilfrid Ennenbach
Hochschule der Bundeswehr

The discussion of "Misconceptions" is based on the hypothesis of a double "logic" in human behavior:

- the "right logic" is based on concepts in which the "Law of Matter" is fully presented (see for example the concept "Invariance of Volume" by Piaget),
- the "psycho-logic" works with analogies which, although understandable and plausible for human beings, partly or not at all correspond to the subject (e.g. animistic, finalistic and artificialistic explanations by Piaget; geocentric theory of the world in ancient times). For the child, this "psycho-logic" has a significant function in orientation (egocentrism according to Piaget), but it also remains important in later life. We all construct our own "theories" in many fields, especially the social - but not only here; we have our own logic, which often prevails over better knowledge.

In this field misconceptions have a key-concept function.

One aim of education is to build up correct concepts, to rectify the inadequate and to secure an appropriate use of it. The quality of the presentation of the subject matter in school is, among other factors, decisive in whether this will happen.

A classic research in the field of "Misconceptions" dated from 1930 (E. Wohlfahrt) is presented as well as researches of the author and a co-author on the effect of model-instruction in biology and physics (12 to 14-year-old students).

These models were constructed in such a way that they correspond to the "Law of Matter" and to psychological basic structures.

Its positive effects on school learning were proved by post-tests, which were given up to six months after the instruction.

In control groups there were found significantly more misconceptions, the number of which increased in proportion to the time elapsed since the instruction; they negatively influenced the quantity and quality of the results.

STUDENT FRAMEWORKS AND CLASSROOM INSTRUCTION

Gaalen L. Erickson
University of British Columbia

Much of the recent literature which has been directed at identifying and documenting students' common-sense knowledge (which I will try to characterize in terms of frameworks) in different subject areas is justified in terms of an assumption that this knowledge has significant instructional import. This paper will address this assumption from two vantage points: first, it will lay out some of the underlying theoretical and methodological issues which pertain to the possible interactions between student frameworks and classroom practice; and second, it will illustrate some of these issues using a series of empirical studies which have been recently carried out at the University of British Columbia.

MISCONCEPTIONS, METAPHORS AND CONCEPTUAL CHANGE: ONCE MORE WITH FEELING

D. Bob Gowin
Cornell University

Why do misconceptions persist? One reason is they feel comfortable, and we can act with them without the mistake costing us very much. To rid ourselves and our students of misconceptions requires us not only to think differently (change our concepts) but to feel, and then, to act differently. But this view is only to say that getting rid of misconceptions is an act of educating that integrates thinking, feeling and acting. (Educating, 1981)

Metaphors are conceptual archetypes that subsume other concepts. A well-struck metaphor also makes us feel something and guides actions. The early stages of scientific inquiry are guided more often by generative metaphors than by arid hypotheses. So, too, it may be the early stages of learning can be guided by subsumptive metaphors. Strangely enough, some metaphors that work out their meanings in helpful ways also appear initially as misconceptions. If I claim "A paintbrush is a pump," your first impression is likely to be that I am mistaken. When, however, I analyze the claim as a metaphor, you will begin to change your mind and see the channels between bristles transport paint like a pump.

The technique of multiple metaphors is described and explained as a way to improve science education

DO STUDENTS UNDERSTAND THE NATURE AND ROLE OF SCIENTIFIC CONCEPTS?

Hugh Helm
Cornell University
(Rhodes University, on leave)

Investigations carried out during lectures to first-year college students of physics and of the humanities suggest that:

(a) physics students may have a poor grasp of the significance of certain familiar equations in elementary kinematics;

(b) given the right conditions, it is possible even for students with no official interest in science to gain some idea of why and how such concepts as acceleration are invented and constructed.

If the above findings have some validity, there is cause for concern about the extent to which students acquire a sense of "what science is all about," and cause for cautious optimism about possible correction of the deficiency. It is suggested that there is room both for continued research into students' perceptions of aspects of scientific epistemology and for experimentation in the teaching and learning of these aspects.

A MODEL OF CONCEPTUAL CHANGE: PRESENT STATUS AND PROSPECT

George J. Posner
Cornell University

A general model of conceptual change is presented, based on the previous work of Posner et al. (1982) and Hewson (1983). The potential applicability of the model is discussed. In particular, three application sites are analyzed. First, the applicability of the model to the study of student learning in various school subjects is explored. A model of conceptual change will be most applicable for those subjects in which students' intuitive frameworks are well developed and inconsistent with accepted theory in the parent discipline.

Second, the appropriateness of the model for the investigation of teachers' thinking will be discussed. In particular, teacher planning and teacher strategies will be analyzed as conceptual change problems. Third, educational change and, in particular, changes in science education, will be interpreted with a conceptual change perspective. The importance of the cultural context of science education will be explained in terms of the conceptual change model.

Finally, limitations and new directions of conceptual change approaches will be discussed. In particular, extension of conceptual change models to include sociological and anthropological analyses will be suggested.

TEACHING FOR CONCEPTUAL CHANGE: SOME WAYS TO GO WRONG

Edward L. Smith and Gerald W. Lott
Michigan State University

Recent research has described a widespread failure of science instruction to effect change in the naive theories students bring with them. This study examined changes in fifth grade students' (10-11 years) conceptions of plant growth and need for light during six weeks of instruction based on a conceptual change strategy. Pre-posttest responses, interviews, observation notes and transcripts of class discussions were analyzed to identify changes in student conceptions and develop grounded interpretations of features of instruction that might account for the results.

The instruction was not very successful in bringing about the intended changes. Three implied assumptions of the conceptual change strategy appear to account for much of the failure: many students were often not attempting to make sense of the phenomena at the intended level of explanation, discussions and observations were frequently not framed in such a way that the intended issues became the focus of attention, and communications and observations were often ambiguous in systematic ways. Theoretical and practical implications of these findings are discussed.

MISCONCEPTIONS AND CONCEPTUAL CHANGE

Kenneth A. Strike
Cornell University

This paper sketches how misconceptions fit into a theory of conceptual change. Conceptual change can be characterized by contrasting it with empiricist views of learning. Empiricist theories of learning emphasize the predominant role of experience in learning. Conceptual change theory, while not neglecting experience, sees learning as the modification of current concepts and emphasizes the role of current concepts in learning. I will discuss three points about misconceptions from a conceptual change perspective.

1. Conceptual change theory can shed light on what it would make sense to mean by a misconception.
2. Conceptual change theory can shed light on how misconceptions can be changed.
3. Conceptual change theory can shed light on the origins of misconceptions.

The paper will give some emphasis to the role of culture (rather than experience) in generating and maintaining misconceptions.

II. INSTRUCTIONAL ISSUES

STUDENT PERCEPTIONS OF EVIDENCE AND INTERPRETATIONS

Robert D. Allen, Walter R. Statkiewicz, Michael P. Donovan
West Virginia University

Practicing scientists are keenly aware of the relationship and differences between evidence (data, observations) and interpretations. Many students, however, fail to clearly distinguish between the two.

Specifically they fail to:

1) recognize that different assumptions can lead to different interpretations of the same observations.
2) recognize the facts they have learned as the products of interpretation.
3) modify accepted facts as new evidence is presented.

Instructional procedures used in the Introductory Biology Program at West Virginia University have been developed to detect the presence of these student difficulties and to assist students to overcome them. Progress is, however, often a slow and frustrating process for both student and teacher. Moreover, these difficulties appear in a variety of contexts suggesting fundamental flaws in the reasoning processes students use when dealing with science. Insight into the basis of these difficulties is provided by the theory of William Perry regarding students' views of the nature of knowledge and the role of authority. Perry's theory predicts difficulties such as those we have observed and offers some explanation for slow progress.

DON'T LOSE YOUR STUDENTS: USE A MAP

John F. Cullen, Jr.
Cornell University

The best way to correct misconceptions is to avoid them in the first place. Concept mapping is a powerful technique to help avoid the formation of conceptual misconceptions. This paper will discuss the philosophy, preparation, and use of concept maps. Examples taken from the author's experience teaching college chemistry will emphasize how teacher prepared concept maps have the potential to help teachers to:

a) make curricular decisions by locating potentially confusing conceptual areas in laboratory experiments, exam questions, lectures, etc.
b) clearly differentiate and integrate similar subject material that is isolated in different chapters of a text or areas of the course.
c) increase student problem solving success by helping to form important conceptual linkages.
d) ascertain what a student knows about a discipline.

IDENTIFICATION OF MISCONCEPTIONS IN GENETICS AND THE USE OF COMPUTER SIMULATIONS IN THEIR CORRECTION

Judith F. Kinnear
Melbourne College of Advanced Education

As with any discipline, the teaching of genetics ideally involves exposing students to learning experiences through which they will meaningfully acquire and elaborate relevant concepts and integrate them into existing frameworks. That the desired outcome is often not achieved can be seen in reports of misconceptions and rote application of rules in problem solving (e.g. Stewart and Dale, 1981).

Through a comparison of students' conceptions of probability in "genetic" and "real life" contexts, this paper will present the view that some misconceptions are due to factors extrinsic to the learner and are engendered as a consequence of limitations and biases in the experiences and materials to which students of genetics are exposed. This paper will also describe a study in which computer simulations were used in a variety of modes to extend traditional learning experiences, e.g. in active data gathering and strategy generation and execution. Through these uses, students' misconceptions were successfully confronted and concepts were refined

Stewart, J. and Dale, M. Aust. Sci. Teach. J. 27 (1981): 59-64.

"DO THEY HEAR WHAT I SAY? AND DO THEY UNDERSTAND WHAT I MEAN"

Charles E. Lamb
The University of Texas at Austin

Communication in the mathematics classroom is of crucial importance. It is through communication that teachers and students interact as a part of the learning process. Whether the communication be oral or written, it is of great importance that students and teachers receive information accurately and the interpret it correctly for application to the learning of mathematics.

As an example, in a teacher-student dialogue there are four things which must occur: (1) the teacher says something; (2) the student hears it; (3) the teacher meant something specific; and finally (4) the student understands it. Clearly, there are several possibilities here for something to go wrong. If this happens, the desired outcome will not be achieved.

This presentation will elaborate on this topic as well as presenting an informal look at common misconceptions in the elementary school mathematics classroom. Possible causes and remedies will be discussed.

INTERPRETING EVIDENCE ABOUT MISCONCEPTIONS

Gerald McClelland
University of Sheffield

Evidence for the existence of alternative frameworks in science has been obtained from interviews with children and from responses to specific tasks. The task of interpretation varies according to the amount of relevant instruction which the child has received and the quality of that instruction. Although children need to be able to cope with the world of experience, this does not mean that they need to develop coherent and interconnected explanatory concepts, unless, for some reason the phenomena involved are emotionally charged and recurrent and, hence, salient to the child. Other ways of dealing with, and talking about, phenomena are suggested. Where instruction has taken place, a lack of refined concepts may be attributed not only to persistent ideas developed earlier in life but to the nature of the instruction itself and to the way in which the task of learning the concepts has been approached.

METALEARNING AND METAKNOWLEDGE INSTRUCTION AS STRATEGIES TO REDUCE MISCONCEPTIONS

Joseph D. Novak
Cornell University

In the past decade, there have been a growing number of research studies showing that students at all ages show a wide spectrum of misconceptions regarding science or other areas of knowledge. Moreover, attempts to redesign curricula or "confrontation teaching strategies" with explicit efforts to make students and teachers aware of misconceptions have usually produced only limited positive results. It appears unlikely that a teacher or curriculum planner armed with a "compendium of typical student misconceptions" could organize a program where such student misconceptions would be markedly reduced. However, the latter alternative deserves to be, and is being, researched further.

Another alternative is to present students with strategies that help them to "learn how to learn" (metalearning) and to "learn how knowledge is constructed" (metaknowledge). We have employed concept mapping as a strategy to help students and teachers understand human learning, and which also contributes to an understanding of knowledge and knowledge production. Vee mapping is a strategy developed since 1977 that employs an heuristic device, the Epistemological Vee, to help students understand the nature of knowledge and the nature of knowledge production.

Studies completed so far suggest that metalearning and metaknowledge ideas can be taught to students from six years old and up. Positive results in terms of complex problem solving have been demonstrated, and research is currently underway to ascertain the effects of these strategies on student misconceptions. At this time, it appears possible that long-term use of metalearning and metaknowledge strategies (over a span of several years, preferably beginning early) could produce students who are qualitatively better learners and who acquire or retain significantly fewer misconceptions. Moreover, these strategies have high promise as aids to design of improved instructional programs.

THE MICROCOMPUTER IN COGNITIVE DEVELOPMENT RESEARCH (PUTTING THE BYTE ON MISCONCEPTIONS)

Terry L. Peard
Cornell University

This paper discusses a study currently being completed to explore the role of the microcomputer in educational research. Two questions are focused upon:

1. How does the microcomputer contribute to meaningful learning?
2. Can the microcomputer serve as a research tool in assessing cognitive development?

This research addresses the learner's reasoning, problem-solving methods, and level of thinking in Mendelian genetics. The microcomputer, interviews, and concept maps are being used to assess the extent of learning and cognitive development. Forty college students from an auto-tutorial biology course make up the sample.

The results of the study will be discussed within an Ausubel-Novak cognitive learning theory framework. Educational implications will be considered.

THINKING IN TWO WORLDS OF KNOWLEDGE

Joan Solomon
Chelsea College

The common meanings of words such as "energy" are context-dependent, and even contradictory, but they are continually reinforced by daily usage and will not die. Even the most accomplished physicists will continue to speak of "cold coming in" and "the rising of the sun." This means that teaching new meanings for concept words will build up a second tier of knowledge coexistent with, but radically different from the first. If misconceptions are to be avoided, our students will need to be able to discriminate between these two worlds of knowledge.

The use of concepts involves the interpretation of everyday phenomena in terms of abstractions. This requires crossing over between the two different domains, explaining the commonplace by means of the symbolic, which is the starting point for every piece of problem solving, and appears to be more demanding than the return to concrete examples. Some recent research with grade 9 students learning about energy will be reported.

IMPLICIT STATEMENTS IN PHYSICS: STUDENTS AND CONSTANTS

Laurence Viennot
Universite Paris VII

The word "constant" may evoke a range of meanings with the two following notions at each end: number, the essential being its numerical value; and a constant function of certain variables, the important thing now being the listing of these variables. In this way, constants appear as a particular aspect of functions of several variables. The results of an investigation among French and Belgian students at the beginning of their studies at University are reported and analyzed. These results show that the usual interpretation of the word "constant" is biased towards the numerical aspect of this notion, at the expense of its functional meaning. Lastly follows a plea for the use of exercises of "text criticism" as pedagogical tools in teaching.

III. RESEARCH METHODOLOGICAL ISSUES

A TWELVE-YEAR STUDY OF CONCEPTUAL DEVELOPMENT USING CONCEPT MAPPING AS AN EVALUATION TOOL

B. Bar-Lavie and Joseph D. Novak
Cornell University

In 1965, the Audio-Tutorial Elementary Science Project (A.-T.E.S.P.) was established first at Purdue and in 1967 at Cornell University. Its purpose was to investigate science concept development in children's minds as well as to test a new method of audio-tutorial instruction. The project adopted Ausubel's "advanced organizers" and "subsumption" ideas in analyzing concept acquisition.

Among others, Whitman (1975), Rowell (1975-76, 1978) and Gurley (1982) used "Cognitive Mapping" and clinical interviews in the A.-T.E.S.P. Ault (1980) improved the interview technique by introducing the Interview "V" Analysis (I.V.A.).

As of today, most of the 250 students that took part in the project have just completed high school, and were interviewed for the last time in the twelve-year study.

In this seminar, we will examine some examples of conceptual maps and misconceptions evolution over the last twelve years. The findings show wide diversity in concept acquisition in grade one and over the twelve-year span of schooling, with both "correct" and persistent misconceptions evident in some students.

USING CONCEPT MAPPING TO IDENTIFY INTERVENTIONS MOST EFFECTIVE IN CORRECTING SCIENCE MISCONCEPTIONS OF PRE-SERVICE ELEMENTARY TEACHERS

Catherine C. Cleare
University of North Carolina at Wilmington

Students enrolled in an elementary science methods course were asked to construct concept maps on a science topic before and after experiencing one or more of the following types of interventions:

1) The instructor graded the concept maps and returned them to the students.
2) The methods students were shown the instructor's concept map containing the same concepts.
3) The instructor presented a lecture on the topic.
4) The instructor involved students in an inquiry activity to investigate the topic.
5) The instructor assigned a reading on the topic.
6) The methods students were required to write a lesson plan to teach the topic to children.
7) The methods students were provided the opportunity to teach the topic to children.

This study examines the effectiveness of these different interventions in decreasing the number of misconceptions about the topic and in increasing the accuracy and complexity of the connections shown on the concept maps.

SOME METHODS FOR MEASURING THE MEANING OF CONCEPT NAMES

Reinders Duit
University of Kiel

Many words used in science as names for concepts are also used in everyday language. Unfortunately, the scientific meaning and the everyday meaning of many of these words are quite different.

When introducing concepts, science teachers have to be aware that the concepts' names evoke a variety of ideas in the students' minds. Science instruction has to take this "variety" into consideration. When planning instruction, the differences of meaning in science and everyday language should be familiar to the teacher or to the curriculum developer.

The purpose of this paper is to deal with the following methods for investigating the meaning of concept names.

1) Association test (the student writes down what comes to his mind spontaneously when confronted with a concept name like energy or work)
2) Definitions (the student describes the meaning a concept has for him)
3) Examples (the student gives an example for a concept)
4) Description of a process (the student describes a simple process using the concept names, e.g. energy, work, force and power).

Theoretical considerations as well as experiences with the methods will be discussed.

INFORMATION PROCESSING INTERPRETATIONS OF ERROR RESEARCH IN LEARNING

Kathleen M. Fisher, University of California-Davis
J. I. Lipson and J. Idar, WICAT Systems, Inc.

By exploiting aberrant forms (mutants), geneticists have gained deep insights into normal cellular processes. Similarly, scientists exploit human aberrations (e.g., brain damage) and mental errors expressed in verbal, written, motor or other behaviors to gain insights into the mechanisms of the mind. This paper reviews recent error research in the domain of mathematics and science learning. Findings are interpreted according to information processing theory. Relevant research on word associations is examined for its potential in reflecting conceptions in distinctive characteristics of the associative network. The aims are to: 1) provide a relatively complete reference to current error research, which is widely scattered in the literature; 2) identify points of convergence and divergence between studies; 3) examine the utility of information processing theory in interpreting errors and vice versa; and 4) to identify potentially fruitful directions for future research.

PRINCIPLES OF ENHANCING RELIABILITY AND VALIDITY OF MISCONCEPTIONS MEASURES

Ron Hoz
Ben-Gurion University of the Negev

Standard psychometric methods are inappropriate to assess the reliability and validity of misconceptions tests. Several principles are proposed for the enhancement of the reliability and validity of an interview in which the student is asked (1) to explain a certain situation, (2) to recall and evaluate partial conflicting alternative explanations, (3) to compare them to her/his own, and (4) to refer to prespecified elements of the alternative explanations. Among the design means are (a) using one misconception in different contexts and different misconceptions in the same context, and (b) using similar but structurally different problems in different arrangements. Among the factors used to enhance the reliability of misconceptions assessment are (1) considering the amount and nature of recall, (2) considering the effects of intervening easier problems, (3) characterizing the ways in which elements of the alternative explanations are treated, and (4) observing their susceptibility to change by presenting easier or more difficult problems.

TESTING HYPOTHESES DERIVED FROM CLINICAL INTERVIEWS

Clifford E. Konold
University of Massachusetts-Amherst

The clinical interview is characterized as a three-stage methodology for formulating and testing hypotheses regarding alternative conceptions. In Stage One, the interviewer formulates hypotheses of a particular student's reasoning and tests these in the form of probes during the interview. In Stage Two, several individuals independently analyze the recorded interviews and then, through a cyclical process of negotiation and review of the tapes, arrive at agreed-upon hypotheses regarding the nature of alternative conceptions. These hypotheses are then subjected to further tests in Stage Three by recycling through another stage of data collection and analysis. These various stages are illustrated with examples from research that explores alternative conceptions of statistics and probability. In one study that will be reviewed a model of probabilistic reasoning was inferred from a set of clinical interviews. Then, specific predictions were made of how subjects, reasoning in accord with this conception, would respond to a different set of problems. These predictions were verified in a second set of interviews with the same subjects.

AN ANTHROPOLOGICAL FUTURE IN SCIENCE EDUCATION RESEARCH?

Herb Lin
Natural Intelligence Labs

The ultimate goal of education research is to improve educational practice. To this end, a great deal of research in science education focuses on the cognitive mechanisms which students use to process scientific information and concepts. This paper suggests that a purely cognitive approach to education research, while useful, is not the only way to understand the educational process. In particular, the fact that science education involves social interactions, both between student and teacher and between professional scientist and classroom teacher, has significant consequences for the understanding of "purely cognitive" information processing mechanisms, and therefore for educational practice. Examples and suggestions for future work will be offered.

STUDENTS' MISCONCEPTIONS IN GEOMETRIC PROBLEM SOLVING

Abraham S. Luchins and Edith H. Luchins*

Geometric problems involving two or three dimensional objects were administered to over 300 high school or college students. Various misconceptions were revealed through analysis of responses and reactions to hints. Some subjects made incorrect assumptions about the mathematical knowledge needed to solve the problems or about their abilities to do so. But misconceptions also arose from the stimulus side and, in particular, from the way the problems were represented. Descriptions of a geometric object which ran counter to the object's structure tended to foster more misconceptions than descriptions of the same object which were in line with its structure. The latter descriptions tended to facilitate solutions and to reduce sex differences as well as differences in responses between mathematics and non-mathematics majors. Suggestions are made for further studies of misconceptions stemming from the stimulus rather than the reactive side.

*Will give presentation at the International Seminar on Students' Misconceptions in Science and Mathematics.

AN EXAMINATION OF STUDENT MISCONCEPTIONS IN GENETICS

Marjory Martin
Victoria College

Research studies have investigated a number of ways of trying to probe and understand the misconceptions of students. One area of biology in which students have learning difficulties is genetics. Students are generally able to mechanically manipulate certain types of genetic problems; however, the more abstract ideas and the interrelationships between those ideas often escape understanding.

In Victoria, Australia, year 12 students undertake an external examination. In 1982, a "new type" of question was included in the Biology examination paper. After being given an example, students were asked to make a diagrammatic representation (concept map) of their understanding of genotype and phenotype and the relationships between them.

This paper reports on the results of the "new type" of question. Sample answers will be discussed. In addition, student and teacher reaction to the question will be presented. The implications for the teaching of genetics and biology will also be considered.

INFLUENCE OF COGNITIVE INSTRUCTION ON MISCONCEPTIONS IN MATHEMATICS AND PHYSICS

Merlyn C. Mehl University of the Western Cape
John D. Volmink, Cornell University

In this paper, an attempt is made to analyze the process-product dichotomy in Physics and Mathematics education. The analysis is made from two perspectives:

(a) The Feuerstein approach to cognitive development as it relates to disadvantaged students.

(b) Gowin's Vee heuristic as a means of gaining perspective of the relation between conceptual and procedural knowledge.

Results of the research are presented indicating the strong influence that these approaches can have on our understanding of how pervasive and deep-rooted misconceptions are.

RESEARCH METHODOLOGY IN INVESTIGATIONS OF STUDENTS' CONCEPTIONS IN SCIENCE

David G. Schuster
University of Natal

Investigators use various methods, including individual interviews and written questions, to probe students' conceptions in science. The methods can involve several difficulties, assumptions and pitfalls. Unless these are recognized, the validity of the findings may be uncertain. The methodology and precautions of research in the social sciences need to be considered in research on student conceptions.

Among the difficulties involved in investigations of conceptions are the following:

- Presence of confounding variables
- Lack of controls
- Effect of the theory base, expectations, and subjectivity of investigator
- Unrecognised complexities underlying apparently simple physics problems
- Semantic problems, including multiple and variable meanings, meanings which vary with context and different meanings to subject and investigator
- Premature conclusions and categorisations, especially from written texts
- Insufficient depth of probing, and need for mapping of schemata
- Concept modification during interviews
- Demand characteristics of the investigation situation
- Effect of mode of presentation
- Cues, prompting, and suggestibility in interviews
- Need to check inferences and conclusions with subjects

These difficulties complicate cognitive studies of students' conceptions, and suggest the need for care in the design of investigation procedures, and caution in the interpretation of response data.

Results of the research are presented indicating the strong influence that these approaches can have on our understanding of how pervasive and deep-rooted misconceptions are.

NATURAL TENDENCIES IN ANALYSING STUDENTS' REASONINGS: TWO INSTANCES IN MECHANICS

Laurence Viennot
Universite Paris VII

This paper points out the main tendencies of experts in analysing students' mistakes, and illustrates these tendencies on two instances in the field of mechanics. It is shown that common interpretations of students' comments built in the very terms of the accepted theory may erase some important aspects of spontaneous reasoning which are illustrated in this paper with results obtained at college level.

IV. HISTORICAL AND EPISTEMOLOGICAL PERSPECTIVES

MISCONCEPTIONS MISCONCEIVED: USING CONCEPTUAL CHANGE TO UNDERSTAND SOME OF THE PROBLEMS PUPILS HAVE IN LEARNING SCIENCE

George Hills
Queen's University

The problem I want to explore in this paper is one I take to be very closely linked to the central concerns of those engaged in the type of research being discussed in this seminar. More specifically, it has to do with using some of the insights deriving from recent work in the history and philosophy of science as a way of gaining a better understanding of the problems and pitfalls encountered by children and adolescents during their initial encounters with scientific concepts and theories. These youngsters are in a rather different position from those, slightly older and more experienced perhaps, who have already gotten on the inside of, and have achieved some level of understanding and proficiency in, one of the conceptual schemes in the sciences. In the case of the initiated, we at least have an understanding of what they know when they have caught on to the kinetic molecular view of heat, the rudiments of evolutionary theory, or Newtonian mechanics. We know something of the content of their views because we understand the theory. Of course, we know more than this. We know something about where these views have come from. And we're learning more about how they have developed, the circumstances under which one theory may replace another, the standards used in judging the adequacy of competing theories, and so on. Now all of this, especially the latter - concerning the nature and development of concepts and theories within the unfolding traditions of science - stemming in part from recent work in the history and philosophy of science, seems to hold great promise for illuminating the problems students experience in learning science. Nevertheless, at present, it shows most promise as one way of illuminating the problems of those on the inside of well understood concepts or theories (cf. Posner, Strike, Hewson, & Gertzog, 1982). The reason for this is that the work done in this field to date has tended to focus on the growth of, and the relations between, concepts and theories *within* the scientific community. Thus, for example, the influential works of Popper (1959), Kuhn (1970), Lakatos (1970), and Toulmin (1972), are *primarily* concerned with the domestic affairs of science and to a very much lesser extent with its "foreign relations."

Of course, none of this is meant to deny that this same body of research also holds out considerable promise as one way of getting to grips with the obstacles confronting the uninitiated. But there are special problems here too. The primary one is the simple fact that we possess little in the way of an explicit and systematic appreciation of the content of the concepts, beliefs, and so on, that they bring with them to their formal encounters with science education. Indeed, I take it that the great virtue of the recent work done on the views of children and adolescents is that it has gradually begun to dispel some of the ignorance and prejudice that has too long beclouded our understanding of these matters. However, in the absence of more comprehensive and systematic knowledge of this kind, we must be on our guard against the tendency to adopt the framework of conceptual change and theory development in an "all out" or unqualified way. That is, by simply taking it for granted that pupils are immature scientists, that they are animated primarily by a concern with *scientific* truth, consistency and explanatory power, and, in consequence, that their views are properly assessed in terms of their adequacy from a scientific point of view. (And if caution is to be urged in understanding the problem, it must be doubly urged so as to avoid premature and ill conceived attempts to solve it.) Prior to the wholesale adoption of any such high-level explanatory framework, we require studies providing us with more detailed portraits of the kinds of concepts, beliefs and views that pupils command, along with better pictures of the ways in which and the circumstances under which they are put to use. On the other hand, while much of the yield of previous research is highly suggestive, it is nevertheless fragmentary. This makes it difficult to know what to make of the views pupils espouse. Do they represent a position in which they have some continuing stake? Or are they transient artifacts of the research design, including the tasks employed, the questions asked, and so on? In short, what is essential if talk about conceptual change and theory development and so on to gain a proper purchase on the perspectives of those who are not yet on the inside of some part of the scientific framework, is some basis for thinking that the beliefs they espouse form a more or less coherent view on the topic in question, that the view has scientific purport and, therefore, that it is appropriate to characterize and assess the view in terms of standards appropriate to science. Unless such a beachhead is established, any talk about preconceptions, misconceptions and the like is bound to be wide of the mark.

"ARISTOTELIAN" WAS THE ANSWER, BUT WHAT WAS THE QUESTION?

Jean Lythcott
University of Wisconsin-Madison

The label "Aristotelian" was first introduced as an adjective for the pre-instructional knowledge of children with a great deal of caution. Now, four short years later, the label is used quite freely, though still with some degree of caution by some researchers, to describe whatever it is in the minds of children which is non-Newtonian. Further, a pattern of nomenclature has been accepted, a convention for labelling pre-instructional knowledge in the minds of students by an historical referrent.

Clearly, the facilitation of communication between researchers is one good reason for widespread acceptance of such labels; but it is not a sufficiently good reason. These labels are very meaningful; they are not consciously non-meaningful as is quark from particle physics. If the labels are to be accepted then their meaningfulness should be accepted also.

Maybe now is the time to ask some questions about the validity of the label "Aristotelian" before the convention has such inertia that questioning basic assumptions will seem inappropriate. One question is: In what sense are children who are labelled as Aristotelian, Aristotelian?

The content area usually used in this important work on children's conceptions of motion is free fall, the motion of objects under gravity. The proposition called Aristotelian is not Aristotle's, however, since for him no force at all was involved in such motion.

One possible approach then would be to seek detailed evidence of a content-proposition match between children's conceptions and Aristotle's, in many content areas.

Another question is: Is this to-be-proven match between propositions merely a curious and interesting phenomenon, but without any causal relationship? If so, its establishment would seem to be a waste of time. If, however, causality is to be established, as perhaps in vestigial language remnants, or in some learning theory which assumes that the growth of knowledge in an individual parallels the growth of scientific knowledge in history, it would seem that precise evidence of the existence of such a parallel is a prerequisite.

MISCONCEPTIONS AND MYTHS MASQUERADING AS BIOLOGICAL FACTS

Madhu N. Mahadeva
University of Wisconsin-Oshkosh

The persistence of myths and misconceptions masquerading as scientific facts in the teaching and learning of science is due to several factors. Inherent in the process of the scientific enterprise is the inevitability of myths and misconceptions. These errors may have originated as heuristic or speculative tools quite legitimate to the scientific method. Such intellectual tools, however, long outlive their utility and persist as intractable myths.

Another factor is our reliance on writers of textbooks who with patience and perseverance package an immense mass of information which often inadvertently includes such errors. Authors of textbooks are retailers of information using materials that have been produced by innumerable research scientists, past and present. Often these scientists, too, may be victims of erroneous preconceptions.

Among such myths and misconceptions, some are esoteric whereas others are widespread and commonplace. Examples of those that are esoteric include sophisticated concepts such as gene, mutation, species, et cetera, concepts which are inculcated by teachers and textbooks. Ideas relating to such concepts as race, intelligence, evolution, et cetera are examples of widespread myths acquired from parents and society at large which, of course, includes educators.

The present paper will examine a number of these myths and misconceptions, both esotoric and commonplace, that bedevil the teaching and learning of biology.

CONCEPTUAL CHANGE IN SCHOOL SCIENCE: A REVOLUTIONARY OR EVOLUTIONARY PROCESS?

Joseph Nussbaum
The Hebrew University of Jerusalem

The proposed analogy between the history of science and the conceptual development of the individual has become widely accepted by researchers who investigate students' "misconceptions" or "alternative frameworks." They believe that this analogy may provide us with better insight into the psychological processes which take place in science learning. However, the history of science is not a field which is governed by one monolithic approach. Historical accounts may vary, depending on the philosophical commitment of the researcher. Thus, one who assumes that such an analogy is valid and potentially helpful for educational research should be more specific in indicating the specific approach in history of science that he adopts. He should examine this approach for all the potential implications it bears for education.

In this paper, the argument will be made that the reference made by many science researchers to Kuhn's revolutionary account of the development of science ideas may not be suitable. This may be so if we accept the rival evolutionary account, given by people like Toulmin and Lakatos.

The author's studies of children will be reviewed as supporting the evolutionary approach. Some of the practical implications which evolve from adopting an analogy with the evolutionary approach, in the history of science, will be considered.

ALTERNATIVE CONCEPTIONS OF THE TENTATIVE NATURE OF SCIENTIFIC KNOWLEDGE

Margaret A. Waterman
Emory University

Scientific knowledge is characterized as tentative, as having the capacity to be changed under appropriate conditions. Because the methods of inquiry in science are inextricably linked to their product, knowledge, the task is to understand those linkages which make scientific knowledge tentative. The controversy-rich philosophy of science literature provided theoretical background for this study of issues in epistemology of science.

Twenty-nine college biology students were asked to comment on statements about scientific knowledge which reflected one of two views of science. Students' accounts of the growth of knowledge and of the nature of objectivity in science revealed alternative conceptions of some of the bases of the tentativeness of scientific knowledge. Three general themes about scientific knowledge emerged from the comments: (1) it is an unchanging accumulation of empirically discovered facts; (2) it is tentative because of new evidence arising by new equipment and techniques; and (3) it is theoretical, a human construction based in part on theory-guided and theory-limited observations.

V. ELEMENTARY SCHOOL SCIENCE

ENGAGING CHILDREN'S INTUITIVE PHYSICS CONCEPTS VIA CURRICULUM UNITS: THE CASE OF HEAT AND TEMPERATURE

Sidney Strauss
Tel-Aviv University

A series of studies was conducted to determine the development of children's intuitive understandings of the concepts of heat and temperature for the purpose of devising a curriculum unit that engages these intuitions.

Among other things, the first study mapped out how 180 children ages 3-14 understood the intensive physical aspect of temperature. It was found that very young children solved the tasks correctly, older children solved the same tasks incorrectly, while still older children solved them correctly.

In the second study, we exploited a conflict between children's correct intuitive understandings of intensive physical quantity (cold water when mixed with more cold water yields water at the same temperature) and their incorrect understanding of the same concept when presented numerically (water at 10°C when mixed with water at 10°C yields water at 20°C). Three age-related ways of dealing with this conflict were found.

A curriculum unit was revised by incorporating the above into the unit. A third study tested the effectiveness of the unit and it was found to be as effective as individual instruction and more effective than a control group.

MISCONCEPTIONS IN ELEMENTARY SCHOOL SCIENCE - A KELLYIAN PERSPECTIVE

Alan E. Wheeler
Brock University

The distinction between students' intuitive understanding of their world (students' science), and the conceptual understanding of science held by the science teacher (scientists' science) is illustrated using the concept of energy in elementary science. Aspects which characterize students' science (e.g. animistic thinking), often considered incompatible with traditional scientific "objectivity" are interpreted from a Kellyian perspective. Implications for science teaching using a "constructive alternativist" philosophy are explored in the paper.

VI. PHYSICS

STUDENTS' ALTERNATIVE CONCEPTIONS OF MECHANICS

John J. Clement
University of Massachusetts, Amherst

Data from written tests and video-taped problem solving interviews show that many physics students have a stable, alternative view of the relationship between force and acceleration. This "conceptual primitive" is misunderstood at the qualitative level in addition to any difficulties that might occur with mathematical formulation. The misconception is highly resistant to change and is remarkably similar to one discussed by Galileo, as shown by comparison of his writings with transcripts from student interviews. The source of this qualitative misunderstanding can apparently be traced to a deep seated preconception which makes a full understanding of Newton's first and second laws very difficult. In such cases learning becomes a process in which new concepts must displace or be remolded from stable concepts that the student has constructed over many years.

ENERGY CONCEPTIONS HELD BY STUDENTS AND CONSEQUENCES FOR SCIENCE TEACHING

Reinders Duit
University of Kiel

Energy education has become an area of major interest within school learning. Science instruction, especially physics instruction, is expected to take care of the basis, the physical concept of energy. Empirical studies on learning the energy concept in physics instruction reveal severe difficulties on the part of the students to grasp this concept. The results of these studies point out that it seems to be unlikely that many students - during physics instruction - gain a concept of energy which is indeed useful for understanding the energy problems of society.

I would like to outline some studies which have been carried out at the IPN (Institute for Science Education) on learning the energy concept: 1) a study on the formation of energy ideas during cognitive development (done in the Piagetian manner); 2) studies on learning the energy concept through an instruction unit and in the course of four years of physics instruction (using interviews and questionnaires); 3) a small study on applying the energy concept outside of physics classrooms (the students were asked to write an essay on energy in German class). Some consequences for science instruction as well as some general considerations on learning science knowledge will be discussed.

ADVANCED PHYSICS COURSES DO NOT PROVIDE STUDENTS WITH CONCEPTUAL CHANGE

Guy Faucher
Ecole Polytechnique
Montreal

Students can pass through introductory physics courses without acquiring a sufficient conceptual knowledge of physics. It is often assumed that this will be provided by more advanced courses. CON-PHY-TEST has been developed to evaluate at what level basic concepts of mechanics and electricity and magnetism are grasped by students. It has been administered to sophomore and senior engineering physics students, whose performance in standard, quantitative physics exams is better than that of non-physics majors. The results of the test have revealed a low qualitative understanding of physics, with only a slight difference in favor of senior students. Though some researchers have pointed out that even physics majors may have conceptual problems, the situation may be more profound. Implications for introductory physics instruction are suggested.

IDENTIFICATION OF CERTAIN PRECONCEPTIONS THAT HINDER SCIENCE LEARNING: EXAMPLES INVOLVING ELECTRIC CIRCUITS

Elsa Feher
San Diego State University

This paper will give examples of student interviews on matters related to simple electrical circuits and will describe various types of preconceptions encountered. Among these are preconceptions based on: previous experience with similar physical phenomena, analogy with different physical phenomena, animistic conceptions, and moral determinants. It appears that the presence of the last two types of preconceptions plays a role in the inability of some students to carry out simple predictive tasks. Excerpts from our interviews will be used to illustrate the relationship between these subjective preconceptions and the students' difficulties in making correct predictions.

NOT ALL THE WRONG ANSWERS STUDENTS GIVE REPRESENT MISCONCEPTIONS: EXAMPLES FROM INTERVIEWS ON GEOMETRICAL OPTICS[*]

Fred M. Goldberg[+] and Lillian C. McDermott
University of Washington

When confronted with a task that involves manipulation of a physical apparatus or a judgment or prediction about a physical phenomenon, students often respond incorrectly. Furthermore, the ideas expressed are often in conflict with the principles of physics. We believe that these incorrect ideas should be considered misconceptions only if a student makes use of them consistently to explain actions or responses to several different but related tasks. Using this criterion, we will describe some misconceptions that students have about images in mirrors and lenses. Our discussion will be based on the results of over 100 individual demonstration interviews that we have conducted this year with students enrolled in college level introductory physics courses. We will describe several interview tasks, illustrate typical incorrect responses with excerpts, and discuss methodological difficulties concerning the interpretation of the data.

[*] This work was supported in part by the Research in Science Education (RISE) Program of the National Science Foundation, Grant No. SED81-12924.

[+] On leave (1982-1984) from West Virginia University, Morgantown, WV.

THE EFFECTS OF MISCONCEPTIONS OF SPEED AND TIME ON THE SOLUTION OF SPEED PROBLEMS

Ron Hoz and Malka Gorodetsky
Ben-Gurion University of the Negev

High school students were found to have the following misconceptions regarding the speed and time concepts: Speed is an extensive rather than an intensive quantity; time is not a necessary mediator in situations that involve speed; replacement of the nonexistent three-concept relationship $S = vt$ by two-concept direct and inverse (not strictly proportional) relationships; and nonrecognition of the distinction between local and global features of concepts and their relationships. These misconceptions resulted in ten incorrect solution strategies that were employed in the solution of algebra speed problems involving uniform motion of two cars, each with two speed and direction changes. These forward strategies were schema driven, had a bottom-up nature, employed time-independent quantities, capitalized heavily on chance numerical relationships rather than on three-concept formulas, and did not distinguish local from global considerations.

MISCONCEPTIONS IN PHYSICS AMONGST NIGERIAN SECONDARY SCHOOL STUDENTS

U. M. O. Ivowi
University of Lagos

The existence of some misconceptions in physics amongst secondary school students in Nigeria has been studied and compared with a similar study elsewhere. A test on multiple choice items in physics concepts was administered to a group of students in selected schools believed to have adequate facilities in both human and materials to enable physics to be taught effectively. Teachers of physics in these schools were interviewed and also required to respond to the test. Two major causes of misconceptions in physics amongst students have been identified as teaching and available textbooks. Some suggestions towards improvement have been made.

HOW SWEDISH PUPILS, AGE 12-15, UNDERSTAND LIGHT AND ITS PROPERTIES

Christina Kärrqvist
Göteborgs Universitet

The history of ideas shows that it has taken mankind 2000 years to formulate the key idea of optics, that is, that light is a physical object that propagates in space, apart from sources and effects. We ask to what extent Swedish school pupils, 12-15 years of age, use the key idea of optics, what they imagine the link between object and eye to be, and how they explain a phenomenon of refraction and the effect of a coloured filter of light. Our questions are answered by allowing about 600 pupils to write down their solutions to four optical problems and in doing so explain how they think. A qualitative analysis is made of the explanations, and this shows that for each problem given, about 30% of the pupils apply the key idea of optics after attending lessons.

STUDENT PRECONCEPTIONS IN INTRODUCTORY HIGH SCHOOL PHYSICS AS RELATED TO COURSE ACHIEVEMENT

Heidi Kass and Pamela Lambert
University of Alberta

The nature and extent of preconceptions pertaining to Newton's First and Second Laws of Motion held by beginning grade ten physics students prior to formal instruction in the topic was explored and related to end-of-course marks and criterion test achievement.

Forty students randomly selected from classes in four high schools were each presented with four tasks in an individual interview setting: horizontal motion along a groove, inertia of a ball in a cart, inertia in space, and acceleration produced by a constant force.

Protocol analysis revealed that only approximately one-third of the students expressed conservation of motion or perception of motion relative to an external frame of reference, many of the other preconceptions reflecting Aristotelian views. Gravity was used to explain the inertia of a stationary or a moving body in nearly half the instances. The vertical force of gravity was also thought to retard horizontal motion.

While girls performed at a significantly lower level than boys on each task, they scored significantly better in end-of-term marks ($p < 0.05$) but not on the concept-related criterion test.

REINVENTING ELECTRICITY

Melvin S. Steinberg
Smith College

Recent research suggests that "Current is the primary concept used by students, whereas potential difference is regarded as a consequence of current flow, and not its cause."[1] This major conceptual difficulty appears to be largely independent of prior instruction in static electricity. As a remedy, I propose exploring electrostatic phenomena in circuit contexts through hands-on experimentation employing miniature light bulbs as current detectors and large-value capacitors as sources of variable potential difference. A lecture-demonstration will illustrate some of the possibilities for fostering an effective conception of electric potential. Ways of dealing with such misconceptions as light bulb = electric sink,[2] resistor = current catcher,[3] and wire = propertyless conduit[4] will also be considered.

[1] R. Cohen et al., *Amer. J. Phys*. (in press).

[2] Norman Fredette and John Lochhead, *Phys. Teach*. 18 (1980): 194.

[3] Emily van Zee et al., AAPT meeting in San Francisco, Jan. 27, 1982.

[4] Norman Fredette and John Clement, *J. Coll. Sci. Teach*. 11 (1981): 280.

AN EXAMINATION OF STUDENT INCONSISTENCIES IN THEIR UNDERSTANDING OF TRAJECTORY MOTION

Robert J. Whitaker
Southwest Missouri State University

This author's recent article in the *American Journal of Physics*[1] reported an analysis of college students' responses to six questions on trajectory motion. Examples of "incorrect" reasons for "correct" answers were provided in the discussion, but these were not studied in detail. This paper will extend the analysis of this aspect of the study.

[1] R. J. Whitaker, *Am. J. Phys*. 51, 352 (1983).

VII. BIOLOGY

THE ACQUISITION OF CONCEPTS AND ALTERNATIVE INTERPRETATIONS ABOUT THE HUMAN CIRCULATORY SYSTEM

Mary W. Arnaudin
University of North Carolina-Wilmington

This study was aimed at uncovering the valid concepts and alternative interpretations which students in grades 4, 5, 8, 10, and 13 hold about the human circulatory system. The research progressed in two phases: a constructive phase followed by a validation phase. The constructive phase employed interviews and concept maps to construct a conceptual inventory of beliefs from 50 students. The validation phase involved the administration of a written instrument (n = 195). The instrument was developed from the interview protocol and the resulting conceptual inventories. The relative frequency of responses for each belief category for each grade level revealed that the alternative interpretations offered by elementary students persist in the higher grade levels. Students' statements of certainty in the validity of their alternative interpretations indicated that many of these beliefs are firmly held. It is felt that this catalog of student beliefs about circulation may increase teachers' awareness of students' alternative interpretations and their influence on the development of accurate science concepts.

AMINO ACIDS IN PROTEIN SYNTHESIS - REACTANTS OR PRODUCTS? A PERSISTENT MISCONCEPTION IN BIOLOGY

Kathleen M. Fisher
University of California-Davis

Tests and interviews over ten years reveal a persistent error among genetics and biology students: 45% to 75% are unable to identify a specific product of protein synthesis (activating enzyme) in a list of four items. Most who answer incorrectly choose "amino acids" (a reactant). Student confusion has the following characteristics. Students apparently have difficulty: 1) translating between general classes (proteins) and specific instances (activating enzymes), even when they can recite the litany "Enzymes are proteins"; 2) imagining that a product of protein synthesis (enzyme) is involved in the process of protein synthesis (this seems to violate a preconception of the students that that class which is acting cannot be that class which is acted upon); 3) recognizing where amino acids do come from (ingestion and biosynthesis), a topic only briefly mentioned in texts; 4) making connections between compartmentalized bits of knowledge; and 5) thinking through a logical thought chain in a new knowledge area.

INVESTIGATIONS OF CHILDREN'S CONCEPTIONS IN PHYSICS: WHICH METHOD FOR WHICH RESULT?

Edith Guesne
Universite Paris VII

This paper will discuss the nature of the data which have been collected in our laboratory, according to the different types of investigations we used.

Our investigations have been of two kinds:

1) Studies of children's conceptions at a given moment (for example, at the age when we plan to introduce a given field of physics);
2) Studies of the evolution of children's ideas with a teaching.

To do this, we used different techniques: individual interviews, case studies of the conceptual changes of some children working within a standard class or within a small experimental group, large scale studies involving about 600 pupils in several classes of the same grade.

These different methods bring informations of different nature, which we will illustrate with examples taken from researches conducted with children aged 11-14.

SELECTED SCIENCE MISCONCEPTIONS AMONGST SOME NIGERIAN SCHOOL CERTIFICATE STUDENTS

Kolawole Soyibo Mibiol*
University of Lagos

Many students often display "incorrect" notions or "misconceptions" in the learning of science concepts. These misconceptions tend to impede their explicit understanding of the particular concepts (and related ones) being learned. This paper attempts to identify and review briefly the major misconceptions students demonstrated on some biological and physical science concepts tested in oral individual interviews. The basic misconceptions on respiration and photosynthesis, in particular, seem to have been implanted by the teacher, since these concepts are absent from the mother tongue of the subjects sampled.

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*The author is greatly indebted to Prof. K. Lovell and Dr. M.S. Gosden of the University of Leeds, School of Education, under whose supervision the research on which this paper is based was conducted.

MISCONCEPTIONS OF OSMOSIS

Darrel L. Murray
University of Illinois at Chicago

The understanding of osmosis presents a significant challenge to many students. Expert conceptions of this physical phenomenon often entail subordinate concepts of concentration, semipermeability and pressure. Misconceptions of any or all of these subordinate concepts may result in erroneous solutions to osmotic problems.

A detailed study of student responses to a wide variety of osmotic problems has allowed us to characterize a number of misconceptions of concentration, semipermeability and pressure. Concepts of concentration and pressure appear to have roots in intuitive experience. Conceptions of membrane permeability are most likely acquired through instruction in science.

Comparative studies, conducted on students prior to and following instruction, indicate which of these misconceptions are most stable and thus require particular instructional attention. Some novel demonstrations and experiments are suggested as a means for modifying persistent conceptual misunderstandings. Finally, two osmotic problems are presented as a challenge to expert conceptions of osmosis.

STUDENTS' MISCONCEPTIONS ABOUT PHOTOSYNTHESIS: A CROSS-AGE STUDY

James H. Wandersee
Dr. Martin Luther College

This presentation will report the findings of a study designed to investigate students' understanding of photosynthesis. A paper-and-pencil instrument (Photosynthesis Concept Test) was administered in 49 schools to a total of 1405 students in grades 5, 8, 11, and 14. The kinds of cognitive difficulties certain aspects of the photosynthesis concept present will be interpreted within an Ausubelian framework.

VIII. CHEMISTRY

CONCEPT MAPPING: A METHOD FOR DETECTION OF POSSIBLE STUDENT MISCONCEPTIONS

John N. Feldsine, Jr.
Broome Community College

Students in a college chemistry class were instructed on the importance of concepts in understanding chemistry and in the technique of concept mapping. Students were assigned to concept map chapters of their textbook and given other mapping assignments. Students were also interviewed three times during the semester and after the course ended. The data showed that key misconceptions could be identified and that in general, concept maps were good representations of the students' knowledge of chemistry, as confirmed in part by later interviews with the students. Students found that concept mapping was difficult but that it helped them to gain understanding, and to identify some of their areas of confusion.

IX. MATHEMATICS

ARE MISCONCEPTIONS MISCONCEIVED? SOME MATHEMATICAL, EPISTEMOLOGICAL, PSYCHOLOGICAL AND PEDAGOGIC RESERVATIONS

William Higginson
Queen's University at Kingston

In some ways the "misconceptions" perspective is a recent and promising jumping-off point for research in science and mathematics education. It is possible, however, to argue that the approach has a number of major weaknesses, particularly at the implementation stage. In this paper, a case will be made for "misconceptions" as more a part of the problem than as part of the solution. Reference will be made to the theoretical work of, inter alia, Papert, Piaget, Polanyi, Polya and Popper and to research on children's conceptions of mathematics.

JUST PUTTING DOWN NUMBERS: THE CHILD'S (AND TEACHER'S) DEFINITIONS OF "LEARNING MATH"

Harry Osser, Floyd Rudmin and Molly Sorensen
Queen's University, Kingston

What cognitive and metacognitive resources does the child use to make school mathematics meaningful? The procedures employed to answer this question were a combination of classroom observations of a series of elementary mathematics lessons and interviews with the children and the teacher following the lessons.

The interview questions were posed to the children as they worked on math problems and were designed to reveal each child's (1) definition of the task; (2) evaluation of the type and difficulty level of the problem; (3) selection of an algorithm; (4) choice of aids; (5) recording of intermediate values; and (6) mode of checking the results.

The results indicated significant differences between the teacher's and the children's values, concepts, guiding theories and problem-solving strategies in doing math. These differences will be discussed in detail.

MISCONCEPTIONS IN MATHEMATICS AND IMAGERY

Arthur Powell
Rutgers University

Misconceptions are misunderstandings which are based upon incorrect meanings. Since mental representations, or images, precede meaning, then to work on misconceptions necessarily leads one to work on images. A source of misconceptions for learners of mathematics can be their lack of insight in or the insufficiency of their images of the mathematics with which they are dealing. Without adequate images, it is unlikely that misconceptions, where they exist, can be correctly re-conceived or that very deep understanding of the mathematics can be gained. This presentation will explore how imagination and imagery can be used in generating mathematical knowledge and avoiding misconceptions. Participants will be invited to explore the use of their own imaging powers in learning mathematics, to reflect on that experience, to formulate researchable hypotheses with regard to imagery and mathematics education.

CONTEXTUAL NATURE OF MATHEMATICS

Frances Rosamond
Rochester Institute of Technology
Cornell University

Epistemological issues are inherent in the mathematical tasks of making hypotheses and checking them out, searching for negative evidence and seeking inconvenient facts or posing questions without knowing if answers exist or new methods that will lead to solutions. The contextual nature of mathematical statements is made explicit by the ever-present caution, "Holds true under the following conditions...". The mathematician realizes, at least cognitively, the contextual nature of mathematics and has come to some personal resolution of these issues. Not so with many students who see mathematics as a-contextual and apart from relationships. This session will describe two approaches to mathematics problem solving. One reflects an assumption of an every-day reality of connection while the other assumes an approach of laws and structure.

MISCONCEPTIONS OF MATHEMATICAL SYMBOL SYSTEMS: AN OVERVIEW

Judith E. Sims-Knight and James J. Kaput
Southeastern Massachusetts University

Our research has focused on the difficulties students have in translating the content of a problem into mathematical symbol systems. The crux of such difficulties apparently lies in misconceptions of mathematical symbol systems, i.e., in the failure to appreciate that mathematical symbol systems differ in crucial ways from "natural" representational systems, viz., language and imagery. We started with a problem that requires solvers to write an algebraic equation for a proportional relationship. Fewer than 50% of college students are able to solve such problems. We first explored the source of such errors by manipulating problem content in ways that affect problem difficulty. We found two strong and consistent error patterns. One error type appears to reflect direct translation from a linguistic to a pseudoalgebraic equation, while the other is associated with an imaging strategy. In our subsequent research, we explored the generality of these results in terms of other word problems and related cognitive abilities.

Implications for Teaching From the Research on Misconceptions

Jere Confrey, Mount Holyoke College

In choosing to design and implement a six-week summer program in mathematics for young high school women, after working with a major research institute, I gained firsthand experience in both the promise and the mischief of the relations between research and practice. There was unexpected loss--solitude, professional status, relative security, and protection of a research institute--in my choice of trying to "make a difference" to someone. And I, in turn, inherited the fragmentation, relevance, self-doubt, immediacy, mobility, and promise of the world of practice.

In this paper, I hope to share with you the experience of attempting to transform research into practice and in doing so attempt to raise questions in your minds about what the relationship between research and practice can be. To do so, I will describe the research traditions which exerted the most force on the design of the program, how we interpreted and implemented the philosophy and findings of that tradition, what we can say about the results of the implementation, and finally, what new research questions have been borne of those endeavors.

Before doing so, I wish to discuss briefly a perspective on the relationship between research and practice which for me makes sense of what we were attempting. By using this perspective, wherein reason and practice become two different types of practice, I can think of educational research as neither needing to thirst for "scientific" legitimacy nor needing to be required to prescribe immediate action.

Paul Feyerabend (1978) wrote of two traditions, reason and practice. In this context, there are perhaps three traditions: theory, empirical research, and practice. For this discussion I am combining the first two in one category, research, and thinking of them as sharing the characteristics Feyerabend attributes to reason. Feyerabend wrote:

> What is called 'reason' and 'practice' are therefore two different types of practice, the difference being that one clearly exhibits some simple and easily producible formal aspects, thus making us forget the complex and hardly understood properties that guarantee that simplicity and producibility, while the other drowns the formal aspects under a great variety of accidental properties. But complex and implicit reason (as in practice) is still reason, and a practice with simple formal features hovering above a pervasive but unnoticed background of linguistic habits (as in reason) is still a practice. (My parentheticals added.) (p.26)

He described the interaction between traditions in the following way: "We arrive at the idea of a guide who is part of the activity and is changed by it." Thus, he concluded, "Again the problem is not the interaction of a practice with something different and external, but the development of one tradition under the impact of others." (p.33)

Thus, research and practice are two traditions, and when they are juxtaposed, both are affected--when working within one, the other can act as a guide--but there is eventually and happily an interaction which changes meanings within both the traditions as they resonate with and reverberate against each other. It is the merging and juxtaposition of research and practice which gives the SummerMath program, a six-week program for young women in high school, its uniqueness and makes its lessons of value to educational researchers. For nine months the program is planned, and the simple, formal models from research provide our way of looking. Then, for six cacophonous weeks, we are submerged in practice as those models are buffeted about. As we slowly emerge from the activity, we find both our views of the research and the practice have changed as we assess how effective the models and predictions from research were in making sense of our experience and as we plan for the future.

After describing the SummerMath program I will describe how current research was used in designing, implementing, and evaluating a six-week summer program in mathematics. To do so, I will describe the SummerMath program briefly; indicate how the research on misconceptions guided the program development; describe what we know about the effects of the program; and then describe specific new questions which need examination as a result of implementation of this research.

Program Description

In the summer of 1981, Mount Holyoke College decided to develop a summer program in mathematics for high school students. The goal of the program was to encourage young women to gain an understanding of mathematics in order to increase their participation in mathematics and mathematics related fields. The program was also intended to implement the findings of current research from the cognitive studies of students' misconceptions and the research on the participation and performance of young women in mathematics.

The staff of the program includes a number of educational researchers. As Director, I came to the program from the Institute for Research on Teaching, with an intent to implement and evolve further the findings on the learning of mathematics. Jack Lochhead was primarily responsible for proposing SummerMath to the administration of the College. Besides Jack, a number of other members of the Cognitive Development Project at the University of Massachusetts participated in curriculum writing and instruction, including Peter Rosnick, John Clement, Pamela Hardiman, and Ronald Narode. Other major contributions to the curriculum were made by Richard Upchurch, Debbie Schifter, and Felicity Callahan. A clinical psychologist, Dr. Patricia Romney, conducted the workshops in math anxiety. In our current planning for a companion program, SummerMath for Teachers, Joan Mundy has shared in frequent discussions with me on the topics discussed in this paper.

Unlike so many summer programs, SummerMath is targeted at students who are academically capable but for whom mathematics is a hurdle. These students are neither remedial nor gifted and talented. Many are likely to avoid mathematics or to be anxious about mathematics. They may not be representative of a math-anxious population, because in choosing to attend most have recognized this tendency as a weakness and are committed to changing it. Of the forty responses received on the evaluation conducted six weeks after the program, 89% indicated that it was their choice to attend. I suspect the percent would have been lower prior to participation.

SummerMath is a six-week summer program which is devoted to the improvement of mathematical understanding. The curriculum focuses on teaching students to construct mathematical ideas for themselves and is in sharp contrast to materials designed to achieve skill performance only. The students in SummerMath 1982 enrolled in three one and one-half hour courses which met five days per week: Fundamental Mathematics Concepts, Computers, and Laboratory Activities. The philosophy behind all curricular materials and the instruction is constructivist in that students are expected to participate actively in all the learning experiences; the focus is on the processes of analytic and mathematical thought. Such an approach requires students to search for patterns, express those patterns precisely in language and in symbols, and generalize those patterns to new contexts.

In Fundamental Mathematics Concepts, topics from arithmetic, algebra, geometry, and trigonometry were studied. The materials were designed to press for conceptual understanding rather than memorization by stressing a few essential concepts: patterns, unit, number, ratio, and function. In the materials, puzzling problems were used to create a developmental need to revisit or explore new concepts, and the emphasis was placed on process rather than on getting an answer.

In the computing section of the SummerMath program, graphics were used to teach programming concepts and to motivate mathematical insights. The students used twenty-one Apple II Plus computers with the language LOGO, which was developed by Seymour Papert (1980) and his colleagues at M.I.T. Students were encouraged to pursue independent projects as they learned the concepts of computing, such as modes, variables, procedures, and recursion.

In Laboratory Activities, students learned to see mathematics as integral to other fields: geography, astronomy, statistics, biology, and environmental studies. Groups of students began by working on problems designed by the staff and learned to discover problems of their own making. Learning to ask good questions and pursue mathematical insights was essential to this component of SummerMath.

The program's staff was particularly concerned with increasing the participation of women in mathematics. Of special concern were the factors which discourage women from continuing their education in mathematics. One of these was the belief that mathematics is better suited to males as a career option and hence unnecessary for the future aspirations of women (Armstrong, 1979; Fennema, 1977). Another was that ability and not effort accounts for success in mathematics (Wolleat, et al. 1980). These factors were countered by a concerted effort to discuss the attitudes of the young women toward mathematics and to provide career counseling.

Other aspects of the program included both a recreational and an arts and crafts program. In the arts and crafts program, mathematics and art were united as students created quilting squares, pounded out leaf designs on textiles, made cooperative murals, and constructed geodesic domes and kites. Speakers and evening workshops were also available on topics such as astronomy, hydropower, geology, mathematics education, women and mathematics, and underwater acoustics. For students with a history of mathematics anxiety, a clinical psychologist offered counseling on techniques to relieve anxiety.

Research into Practice

There is a moral dilemma for researchers and teacher educators to face as we document repeatedly the misconceptions students hold about mathematics and the differential effects of our curriculum on young women. We must not only describe the situation as it exists, but we must develop specific methods and perspectives which attest to the fact that it can be changed. If educational research is to become helpful and relevant to the classroom teacher, then we must engage in some demonstration projects. We must test our theories, models, and results in actual classroom settings. We must implement successfully problem solving activities, encourage women's participation in mathematics-related fields in a way which sustains them through the educational system, and supply ways of improving student understanding. Else, we should not continue to advocate these methods in research and in teacher education courses, leaving teachers feeling that failure to implement those methods is their responsibility.. It was the belief of those of us in SummerMath that in the optimal setting of SummerMath, independent from traditional curricula restrictions, removed from the credit and grade system and with a low student-staff ratio, even with severe time constraints, we could make a difference and we could begin to develop curricular and instructional models which were compatible with our fundamental beliefs about the results of educational research.

The research on students' alternative conceptions of mathematical ideas exerted the most profound influence on the design of SummerMath. To describe how the research program influenced the SummerMath program, I will hastily describe what I think we know quite confidently from this work, the tenets we use to interpret and to unify these results which formed the program's philosophy, what we did as a result, and our assessment of the effects.

Research on Mathematics Learning

I will begin by discussing the work on the cognitive processes in mathematics learning. In doing so, I hope to present a list of claims about the research which has been conducted across the various paradigms of cognitive psychology, information processing, and mathematics and science education. From these, I will show how constructivist interpretation of this research has good explanatory and predictive power and is relatively parsimonious. I think that we can agree that the following descriptions of the state of mathematics education are accurate:

1. According to achievement tests, such as NAEP, students perform significantly poorer when asked to solve non-routine problems. Their application of computational skills to word problems is also weak (Carpenter et al., 1980).

2. Student errors are not random, but are often predictable. This implies that they have a rational basis. Quantitative studies of these errors frequently provide examples of reasoned and not capricious errors (Ginsberg, 1977; Radatz, 1979; Erlwanger, 1975).

3. Specific topics such as rational numbers, proportions, word problems, functions, equality, limits, and variable have fairly extensive documentation that students possess idiosyncratic meanings for the concepts. These may be either alternative conceptions from those standardly presented or misconceptions (Schwarzenberger and Tall, 1980).

4. In interviews, students describe their reliance on memorizing rules and procedures for solving problems. They further indicate their dependence on imitating examples in the text. Researchers have interpreted this to mean that there is inadequate development of the fundamental concepts (Confrey and Lanier, 1980; Confrey, 1980, 1981).

5. Poor understanding of concepts is also accompanied by weak strategies for approaching mathematical ideas. These weaknesses show up in various descriptions of mathematical processes (Krutetskii, 1976), problem solving skills, and representational systems (Lesh et al., 1980).

6. Students hold conceptions of mathematics and mathematics learning which discourage conceptual development and the strengthening of the processes. They focus on the importance of getting the correct answer; they manipulate blindly without appealing to their intuition, to a representation, or to a concrete case; and they see mathematics as a rigid formal system upon which they have little or no personal claim (Confrey, 1981).

7. Students are unaccustomed to thinking about their own thought processes. When asked to solve problems out loud and reflect on what they have done, they frequently spontaneously respond with pleasure to the novelty of the situation (Lochhead).

In reviewing these statements, the situation for the learning of mathematics seems dismal indeed. This would indeed be so if it weren't for the accompanying pleasures of listening to students solve problems. Researchers in these traditions share the joys of hearing how original, spontaneous, and insightful students can be when provided opportunities to describe their thoughts; and these researchers are becoming aware of how students attempt to make sense of mathematics--even if the results of those efforts are not the ends for which we hope. We hold the firm belief that it is not students' lack of willingness or ability which hampers the development of mathematical insight, but rather the lack of opportunity and encouragement.

Perhaps the last statement is overstated. The ties between these seven descriptions of students' understanding of mathematics and instruction as it takes place in classrooms are unknown. Very little research has been conducted that connects these outcomes of our educational processes to mathematics classrooms. Research on the activity of teaching and learning in classrooms, when it has focused on particular subject matter, has usually accepted achievement test results as its outcome measure (Good, 1980, 1979; Evertson, 1979). In my opinion, from a fusion of these two traditions, new and profound research can result.

But this is not my task at hand. If these seven claims about students' understanding of mathematics are warranted from the evidence, if their selection represents the current research, and if their presentation is in a language which is acceptable across research paradigms, then I can begin my next undertaking. I want to suggest that alone they do not prescribe action. From them one can conclude that many actions are possible. One can argue that the best action is model of direct instruction wherein a teacher emphasizes concepts and processes, provides non-routine problems, models the use of representation and concrete examples, and so on. (Good and Grouws, 1979). Or, one can argue for a completely individualized program--better programmed instruction which uses our knowledge of student errors (Bork, Plato). Thus, I want to suggest that in order to translate the research into practice, a philosophy or a theory must be used. It must explain these seven descriptions and predict other occurrence not yet examined. If the theory is quite powerful, it should also be possible to begin to build bridges to other subjects. From this, one can begin to chart a course of action. And action, I must hasten to remind myself, is always a response to the current situation; and it is here that practice again comes into play. The question becomes does your research allow you to act in such a way as to make sense of practice, and does it predict what will happen and guide future action.

I want to suggest that a constructivist approach provide such a philosophy. To describe this philosophy I will describe the most fundamental tenet of it, as stated by Glasersfeld (1974):

> A person's representation of the environment, his/her knowledge of the world, is under all circumstances the result of his/her own cognitive activity. (p.22)

This constructivist view of knowledge is in sharp contrast to views that try to reveal some ontological reality rather than to explain how we come to see the world as we do. The implications for teaching and learning are vast; it affects how we portray all four of Schwab's "commonplaces" of schooling: the learner, the subject-matter, the teacher, and the context of schooling.

Within the program, four major tenets followed from this basic assumption:

1. Students, using their previous representations and knowledge, will construct a meaning for what they are learning, and the development of more elaborate and unifying constructions should be encouraged.

2. Our capacity for reflection upon our previous representations and the construction of these representations is essential for developing increasingly adequate constructions and evaluating the success of those constructions. This capacity needs more direct attention in instruction (Confrey, 1981).

3. The current portrayal of the subject matter of mathematics in classrooms is inadequate to promote the development of effective personal constructions. It is portrayed as rigid, absolute, and external, not as a human construction. For instance, problems are not defined against an objective discipline but must be defined as roadblocks to where a student wants to be (Confrey, 1981).

4. Teaching, according to constructivism, requires the nurturing and promotion of more adequate and effective constructions. Although teachers cannot provide constructions for students, they can select what they hope and evaluate to be likely problems to promote the refinement, unification, or elaboration of students' constructions. Teachers, according to this model, are very active, constantly anticipating, interpreting, and testing out their hypothesis about students' construction by questioning and providing potential problems.

5. An individual will also construct representations of the community of others in which s/he resides. Classrooms and schools are such communities, and within these the sharing of personal constructions is undertaken. One can only see another's construction through one's own. Ethics evolve from the perceived relationship of one's own construction and one's perception of the consensus of the collective constructions of others. For example, one's standards of the adequacy of one's own construction is influenced by one's perception of the collective standards of a group. This is a complex issue for constructivism, but one which needs attention. For our purposes, we were primarily concerned with explaining the impact of what is perceived by a student as the community's standards for appropriate performance in mathematics on a student's personal constructions. Issues surrounding terms like authority, power, responsibility, intellectual honesty, and justification are embedded in this tenet.

Given the previous statement of the philosophical basis for the program, we were left to decide what curriculum and instructional methods would be most likely to encourage constructivist learning. I will summarize these.

Curriculum

In writing program materials, we paid close attention to the selection of topics. Because of the students' overreliance on blind manipulation, we chose to avoid algebraic topics for which we could construct no alternative method of insight. Whenever possible, topics could be approached through alternative modes of representation which included: 1) generalizing number patterns; 2) geometric representations; 3) graphing; or 4) experimentation through manipulatives.

We selected both topics to revisit and to explore for the first time. By doing so, we hoped to convince students that they knew less than thought and they knew more than they thought. In revisiting, we chose topics like the area of polygons or slopes of lines, and in exploring we introduced intuitive concepts of limits and trigonometry.

Concepts were stressed and algorithms were constructed and practiced. We talked about what we meant by mathematical concepts and contrasted it with how they had approached mathematics previously. They demanded rules: we refused. They pulled fragments of procedures from memory: we pressed them into admitting they didn't understand them. Together we tore down meaningless routines and slowly began to replace them with personal constructions.

In the materials, students were asked to write out their generalizations both in English and in symbols to help them see how terse mathematical symbolism is. In seeing if they understood a concept, both examples and non-examples were integrated. By asking students frequently to construct problems of their own, we were able to assess more effectively how well that concept was understood.

The materials tried to introduce concepts developmentally. Often a problem was presented in hopes of creating a need for the concept and to act as an advance organizer. Often these problems were chosen to conflict or contradict with widely held beliefs about the concepts, akin to what Posner (1982) describes as "leading one down the garden path." We wanted students to clearly articulate their beliefs and commit to them before we provided what we hoped was to be an inconsistency for them. Other problems were selected for their potential to unify various concepts such as the use of the relationship between pi, the variables circumference and diameter, and the concept of slope.

Krutetskii's processes of generalization, flexibility, curtailment reversibility and information gathering (Confrey and Lanier, 1980) are emphasized in our materials. Word problems were used frequently to increase the accessibility of students' knowledge, to demonstrate the importance of flexibility and comprehension, and to stress the importance of application of knowledge.

The use of LOGO in the computers classes was an important part of the program. The beauty of LOGO is its creation of a slice of the world that students can manipulate and explore and which is rich in potential for mathematical insights. Using LOGO contributed tremendously to the constructivist goals for the program; students set their own goals, learned to think analytically, and obtained immediate feedback on their endeavors

They learned to expect to debug programs, and that encouraged them to be more persistent in their pursuit of mathematical ideas. They became less timid about the machines as they realized that they might lose programs or make mistakes, but that the machines would survive their initial ignorance. LOGO is an example of a microworld that nurtures a student's sense of empowerment as she selects the problems to explore and sets the standards for success.

Instruction

The staff of SummerMath is committed to the belief that how one learns mathematics exerts a profound influence over what one believes mathematics is. For this reason, the implications of our constructivist perspective had significant impact on the methods of instruction within the program. We wanted not only to teach students mathematical concepts but also to teach them: 1) how to learn mathematics more effectively, and 2) how to be more aware of their own thinking processes.

To do so, we used a variety of innovative instructional methods. The primary goal at the beginning was to move the center of authority in mathematics from us, the instructors (or the textbook), into the student herself. Surrendering one's own responsibility to evaluate the success and worth of what one is learning is incompatible with our values for constructivism. Students are still constructing when they do this, and perhaps adapting to what they believe are the demands of mathematics instruction in a typical school setting, but it's a weak personal construction. Unless they can successfully avoid mathematics, it will result in severe restrictions on their capacity to represent their experiences.

For example, we used the method of paired-problem solving (Lochhead, 1977). In these methods, in order to communicate to students the importance of active learning the students work in pairs solving problems. One student acts as the problem-solver and the other is the questioner. As the problem-solver solves the problem out loud, the questioner must follow the explanation, asking questions until the method, right or wrong, is clear. The assumptions underlying this method are three:

1. Clearly explaining one's method can often result in increased precision.

2. Errors frequently have a rational basis, and until that basis becomes clear, the remedy seldom succeeds.

3. Students need to become more aware of their own thinking processes.

We treated "errors" as opportunities to gain entry into students' personal constructions. We explored the errors with students asking them to solve a variety of problems as we tried to find a construction that explained the students' responses. We learned to think of students' "misconceptions" from an advanced scholar's point of view, not as "wrong" in an absolute sense, but as "inadequate for the purpose of . . . ."

When students asked a question, we responded with a question. This meant that there might be a considerable wait before we responded as we tried to figure out what the student might be thinking. The role of teacher changed dramatically. We grew increasingly less uncomfortable saying, "I don't know; let me think about it" and frequently requested, "tell me more" as we redefined our roles and became accustomed to original, insightful, and occasionally off-the-wall suggestions by students. We discussed explicitly their beliefs about learning mathematics. We talked about memorization and its results. We tried to communicate that we knew changing survival behavior was a difficult undertaking and that they would feel insecure and inadequate at first. As Dr. Romney, our clinical psychologist, had warned us, "With maladaptive behavior, things often get worse before they get better."

We gave no tests except for placement and evaluation of the program, and no grades. The reason for this is that we were stressing cooperation rather than competition. We wanted students to learn to work in groups so they could learn from each other. The groups and pairs strategies seem to me to be essential to avoid the threat of these methods' becoming overwhelming to the teaching in self-contained classrooms.

Most importantly perhaps of all, in my mind, we minimized the pressure which pace exerts on the traditional classroom. Students were encouraged to pursue a topic until they understood it to their own satisfaction. Cognizant of the research on teaching indicating that a brisk pace is conducive to better achievement scores, we pressed on students to work at a reasonbly high level of involvement. Of course, with an instructor/student ratio of ten to one, we were able to assess students' involvement and to encourage consideration of new but related topics.

Lest it seem that all of these innovative curricular and instructional methods were easily implemented without struggle, hesitancy, difficulty, or soul-searching, let me relate a story about what occurred two weeks into the program. By Thursday of the second week we had a significant portion of the students confused, frustrated, and uncertain. This was not what they expected, and it was not mathematics. The adjustment to this new set of demands had them in turmoil. Our staff met for three hours to decide whether to return to a more traditional program. Most keenly, we debated whether to return to more traditional curricular presentations while insisting on the innovative instructional methods trying to progress to our goals in a more stepwise fashion. We listed their complaints:

1. What is this curriculum good for?
2. This is not real math.
3. This is too easy.
4. This is boring.
5. How will this help me in my: (1) grades, (2) next course, (3) SAT's?
6. I don't know what I am going to learn.
7. This is not what I expected.

When we compared these comments to what we were seeing each day in the classrooms, we conceded that it was not that they were finding what we were asking too easy, but that they didn't know how to construct ideas for themselves. They were evaluating the program according to their previous models for learning mathematics and expecting us to interpret the problems and to tell them the answers. They were not yet seeing the problems as their own, but as ours. Most of all, they were confused as their expectations were not being met.

We called a meeting of the whole group. I led off discussing the research on expectations and the impact of one's expectations on subsequent experience. My staff followed, selecting particular questions and addressing them from the perspective of their course and from the philosophy of the program.

The turnabout was dramatic. From then on we had the students with us--they became enthusiastic and confident. Why it happened, what made the difference, I can't say. In my introductory talk and in the brochure, students had the opportunity to hear the same kinds of statements. Did they simply learn a new sort of jargon? Or was the issue one of readiness and conceptual change? I can't say what accounted for the change in their attitudes and in their engagement in the problems, and I hope through journals and interviews to study this summer.

I interpreted that experience to mean that people who believe in this approach to mathematics learning should not underestimate how radical a change is required by it. Each of Schwab's commonplaces of schooling are affected. The roles of teacher and student are redefined; what is taught and how it is taught are changed; and the purposes and contexts of schooling are transformed.

Evaluation

Material for evaluating the SummerMath program was collected via two student questionnaires, one completed immediately following the program and another sent to the students six weeks after they had returned to school.

The first part of the evaluation asked students about their opinions of the approach used in learning mathematics in the program. Specifically, we asked their opinion on the revisiting of curricular topics, the methods of paired problem solving, the adjustments they foresaw necessary on returning to school, and whether they were more aware of the mathematics requirements in various careers.

When we asked the students if our attempts to get them to see behind the scenes on particular topics were successful, sixty-seven percent of the students indicated that they saw significant, positive differences. Thirteen percent more of them wrote that they saw positive differences, while thirteen percent were ambivalent, and seven percent saw differences which they did not prefer.

When asked to specify topics which they found most insightful, the students showed a preference for our treatment of slopes, the Pythagorean theorem, the introduction of pi, and trigonometry. Also mentioned were the word problems and the emphasis on geometry.

The students who felt positive about the approaches focused their comments on the sense of power and freedom they felt by not having to rely so heavily on memorization. They indicated a willingness to persevere more on a problem, an ability to see a unity among the ideas, a satisfaction from having reasons to believe in mathematical truths. They wrote, "I think above all I noticed relation and unity between mathematical concepts" and "The difference was the way we learned it; it was memorized whether it was right or wrong. But the way you presented it, for us to convince you of the fact that it was true, made a big difference." Sadly, one student wrote, "Our teachers don't care about us understanding math concepts; they are more concerned about us passing their exams."

Of the students who did not prefer our approach, most indicated that the pace seemed too slow or that they already knew the information behind the scenes from their previous instruction. One student wrote, "To remember how to do the procedures is harder than to remember the formula." For this student, we clearly were not successful.

We asked students if they foresaw changes they would have to make on returning to study mathematics in their schools. Fifty-seven percent said they would make major changes; twenty-five percent indicated the need for minor adjustments, and eighteen percent said they foresaw no changes necessary.

Of the majority who expected significant adjustments, the students predicted a need to ask more questions in class, to look deeper and longer into problems, to visualize the problems, to look at the concepts and not just the formulae, and to demand reasons. A number of the students commented on the need to work at one's own pace and the difficulty of doing so in their regular classrooms. One wrote, "We have to find someone patient enough to ask and discuss the reasons why . . . so we can understand it better. Sometimes it takes a long time."

Examples of the comments by students who expected to have to make changes in their behavior follow. One student commented, "I will have to learn to continue to be aggressive with my ideas and questions, and not to be satisfied with a correct answer, but with an understanding I can call back to." Another student wrote, "When a problem is presented, do not go into a panic. Ask yourself questions, experiment, and when you find an answer, ask yourself how you got it." Summarizing the fundamental tenet of all we tried to teach, one student wrote, "I will definitely take more time analyzing the concept rather than plugging in the numbers."

Some students indicated concern that there would be a conflict with the methods of instruction in the regular classroom. Some indicated a determination to change their own behavior, such as one student who wrote, "I will convert what the teacher is saying into a more logical way of thinking. It will mean more work because now I will almost always have to listen to what the teacher says, then reteach it to myself." Others are less confident: "I think that going back to school will be very frustrating. Now that I have seen a little bit of what mathematics can be, I never want to go back to memorizing formulae and solving everything the teacher's way. I will have to keep remembering what I learned here and not let myself slide into old habits. I am also going to demand more from my math teachers, especially in explaining problems." Some students indicate that they will respond to the conflict by accepting the existing methods. One such student wrote, "Even though I learned a lot here, when I go back I will have to memorize and accept things without explanation, at least the ones that are new to me."

Of the students who indicated no need for change, the responses varied. One wrote, "I may be thinking differently than before, but the end result . . . will be the same." Another said confidently, "All the changes have been made already." Or one wrote, "I feel that through your instruction I am able to think more analytically and organize my thoughts better. As for changes, I won't make any; I will employ what I learned here."

When asked for their opinions about the methods of paired problem solving and small group instruction, fifty-six percent of the students said they liked both, twenty-eight percent liked only one type, and sixteen percent disliked the methods. More students were enthusiastic about working in pairs than in small groups. The responses given to this question seem to reflect the importance of considering the sociological aspects of classroom learning as well as the cognitive implications.

The students who liked the paired problem solving wrote comments such as the following: "Working in pairs forces one to explain to her partner, which helps in one's own thinking process. Also, listening to a partner gives one a better understanding of her partner's thinking process. Some of the advantages of paired problem solving are the thought you must put into everything you do, so that you can justify your manipulations to your partner. Being the listener teaches you to question every move and think in logical steps. I think both people become more active in the learning process." Many students liked the method if they were paired with a student who learned at the same pace they did and who shared the same knowledge base.

The students who were less enthusiastic about the instructional methods often raised concerns with the small group work because of the homogenous grouping and further gave some indications that there were peer pressures not to be too studious or too purposeful. Two students expressed a preference in working alone; as one wrote, "I do not work well with other people at all, and this approach was very hard for me, even though I need to learn to work with other people." Fears about revealing inadequacy or ignorance were discussed repeatedly. However, in many of these cases, the students still supported the method and occasionally made comments such as, "It's easier to work with someone your own age, because they're more on your own level."

We asked the students for their suggestions for improving the program. The suggestions which were made repeatedly were to group the classes on previous knowledge, to offer shorter classes, to explain earlier how our goals differ from traditional mathematics classrooms, and to reorganize the Mathematics Laboratory. All of these suggestions, except perhaps the length of the classes, will be enacted in various forms, and the quality of these suggestions reflects the seriousness with which these students undertook the evaluations.

The final question in this section asked the participants if they think of mathematics in the same way as they did six weeks earlier. Sixty-eight percent of the students said that there was a positive change in their way of looking at mathematics. Eighteen percent said there was no change, and five percent said they felt more negative about mathematics. The positive responses indicated that the students now find mathematics more challenging, more creative, and that it can be fun. Others said they were more confident and flexible with mathematics and more likely to persevere in solving a problem. Others repeated their understanding that mathematics is more than just formulae. Three comments represent the range of such responses: "Six weeks ago I didn't want to get on the plane to come here. Now I don't want to go home. For the first week I was scared to get up and go to class because I could never get the right answer in school and I was afraid someone would call on me. I always thought of math as being very mechanical, devoid of curiosity and creativity. Now I know better." "Mathematics can be for thinking and exploration, but that takes time. I've learned to take my time, because if I try hard enough I can solve any problem." "I am more aware now that mathematics is not such an unattainable subject--but something that we can learn and deal with every day of our lives."

Six weeks after the program ended, participants in SummerMath 1982 were sent another evaluation form to complete in order to assess longer term effects of the program. Thirty-six students returned the questionnaire, which included a return envelope addressed to the secretary to preserve their anonymity and a section for their parent(s) to complete. A summary of the students's responses is presented in the next section.

One hundred percent of the students responding indicated that they were enrolled in a mathematics course. Students were asked to rate their level of anxiety prior to entering the program and again after the program had ended to see if they felt less anxious about mathematics. The rating scale went from 1 (most anxious) to 5 (least anxious). The mean score prior to attending the program was 3.6 (standard deviation was 1.3), and it was raised by .5 points to 4.1 (the standard deviation was 1.0) after the program according to the students' assessment.

According to the students' assessment, improvement in students' perception of their potential to do well in mathematics also resulted from the program. Using a five point scale, students were asked to rate their potential to do mathematics before and after the program. The pre-program mean was 3.3 (with a standard deviation of 1.2), and the post-program assessment had a mean of 4 (with a standard deviation of .75).

Students were asked to respond to the question, "In your current mathematics course, your experience in SummerMath has:

1. You are not taking mathematics.
2. Had no effect at all or has been detrimental to how you learn mathematics.
3. Had little effect on how you learn mathematics.
4. Had a significant positive effect on how you learn mathematics.
5. Improved dramatically how you learn mathematics."

Eighty-three percent of our graduates responded to this question with a rating of 4 or better. The mean response was 4.0 with a standard deviation of .57.

We followed this question by asking students to elaborate on their responses if they chose to do so. The following are excerpts from those responses:

The SummerMath program has helped me understand better derivatives in calculus.

In saying that my experience at SummerMath has been detrimental to how I learn mathematics, I don't mean that I now feel less confident. I mean that now that I've seen how well math can be taught I'm frustrated with the way my teacher teaches it. He doesn't teach badly, but I realize that he could teach it better than he does. I am able to do the work and get good grades, but I don't really feel that I know what I'm doing when I write out formulas, identities, etc. I can't see it in my mind. Going to SummerMath has helped me a lot, though, as well. I had only had Algebra II before this year, and I was planning to, and now am, taking trigonometry and geometry. The geometry and trig that we did this summer has helped me in the trig for which I have not yet had the geometry.

Every once and awhile the teacher asks a tough question, expecting no one to respond, and I can answer it.

My current math course is programmed. There are no teachers. Our only resources are some sorry graduate students, some of which speak very little English. The class has a 50% drop rate, and only 25% of the students pass. Before I went to SummerMath I would not have been able to complete a course like this. Currently I am receiving a high B or A.

The change I have noticed in how I learn mathematics is in approaching a problem from more than one direction. If I can't solve a certain problem by following examples of similar ones, I will now go back and try it from a totally new direction. Starting from scratch I use my knowledge of very basic mathematics to work up to the level of the problem and then, hopefully, solve it. Sometimes I succeed, sometimes I don't. Either way I usually end up learning something more about the type of problems and ways to solve them that we are currently studying.

The SummerMath program gave me confidence and a desire to learn mathematics. I learned how to conceptualize this summer, and that has been the most beneficial aspect.

One of the goals of the SummerMath program was to change students' conceptions of mathematics. Many students come to SummerMath believing that getting the correct answer is far more important than understanding the processes involved in obtaining that answer. In doing problems, they would insist on one method and be satisfied with memorizing a single formula for that method. We tried to teach students that mathematics is for exploring and discovering, and that the processes involved in generalizing, guessing, testing, and concluding were a legitimate part of the mathematics.

To see if we were successful, we asked students to rate a series of statements from 1--strongly disagree to 5--strongly agree. (In describing these results, all the questions are adjusted so that a high score indicates a conception of mathematics more in line with what we hoped to achieve. However, they were asked in various directions.) The question and the means and standard deviations of the responses are given below:

1. Mathematics is important for my future. The mean was 4.7 (with a standard deviation of .71).

2. How you get an answer is as important as whether the answer is right or wrong. The mean was 4.4 (with a standard deviation of 1.0).

3. There is more than one way to get a right answer in mathematics. The mean was 4.2 (with a standard deviation of 1.3).

4. Computers are not smarter than people. The mean was 4.1 (with a standard deviation of 1.0).

5. Mathematics is not a bag of tricks. The mean was 4.0 (with a standard deviation of 1.0).

6. Mathematics is not done best all by one's self. The mean was 3.7 (with a standard deviation of 1.1).

Future Directions

The interactions between the past research, as it exists in articles, books, and through the spoken word, and the present practice of SummerMath are complex and enlightening. Research, so far as it is helpful in this endeavor, must help us to make sense of what we are seeing in the rapid pace of the program. It must be interpreted along with its implicit assumptions and values to suggest practices which complement it. Research surely exerted its influence on the progam, and its impact was positive and unifying.

Practice, however, was not simply the passive recipient of this force; and certain problems recurred in persistent patterns--problems for which our current guide or map from research provided no explanation or language by which to describe those events--and so, subtly, stubbornly, these areas tugged at our awareness. It is only now, nearly a year after the clamor of the program has subsided, that I offer now guesses of some of the phenomena which were so perplexing. Undoubtedly much more was also missed, experience so foreign to our traditions of looking that we cannot even speak of what it is.

In this last section, I want to present a set of new issues to be addressed by researchers on student misconceptions. Much of this is provoked by attempting to enact the research in a teaching situation. In general, the call is for broadening the conceptualization of the factors which influence the development of students' conceptual understanding.

1. The label misconceptions seems to imply that misconceptions ought to be avoided, and I think that this connotation of the term is inappropriate. We need to consider a conception as a body of beliefs held by a student which is either effective or ineffective in explaining certain mathematical events. It becomes a misconception only in contrast to our own beliefs which explain more events. Misconceptions and alternative conceptions are evidence that students are active, and we need to concentrate on how to convince a student of their limitations. To attempt to write a curriculum or plan instruction which avoids these misconceptions is to deny some of the fundamental tenets of constructivism.

2. We desperately need to develop alternative methods of evaluating what students understand and what characteristics of independent learners they have developed. We need questions which require students to approach them from a variety of directions, which promote strategies of debugging, plugging in numbers using representations, and tinkering. These questions must be on content which mathematicians consider essential and mainstream, and the measures ideally will illustrate dramatic differences between blind skill manipulators and problem-solvers.

In addition, we need measures of personal competence and independence in doing mathematics problems. Our graduates spoke of increased persistence, autonomy, flexibility, tolerance for ambiguity, open-mindedness, level of engagement, and critical assessment of their own level of understanding. These measures need to be mathematics-specific if we are to convince our most potent skeptics. We must move beyond convincing ourselves--we know the state of mathematics education, and we have some tentative answers. We need help on developing the forms of proof.

3. We need to consider the affective dimensions of conceptions. In trying to decipher what students believe about a certain topic, it is important to remind ourselves that how they feel about that situation influences profoundly what information we receive. At SummerMath, it became obvious that for many students who were "math anxious", we were getting a very poor indication of what they knew and could do. The level of confidence and determination a student has, the attitude towards authority and tolerance for ambiguity are all factors which influence performance in clinical interviews as well as in classrooms. The research on misconceptions needs to consider these personal factors in relation to the factors for conceptual change for which it is searching.

4. If the research on misconceptions is to be enacted in classrooms, the demands on the teacher to provide individual attention are overwhelming. In order to lessen these demands, students need to learn to work effectively in small groups and in pairs. We have only begun to try to develop such methods of instruction, but I believe that they are essential. Part of this demands that in our research, we begin to see the cognitive issues raised in our research in relation to sociological perspectives of the classroom. At present, the mathematics classroom is seen as oriented towards the individual, and competition and not cooperation is foremost. Much of what students do intellectually depends on how they view the classroom in terms of public exposure. I think that the research on students' conceptions needs to consider social issues much more closely.

In conclusion, I am suggesting that we broaden our considerations of how we conceptualize the domain of the research on student misconceptions. I believe that the potential for this research to provide invigorating and creative new models of teaching and learning mathematics in classrooms is great. As we interpret and define its implications for classroom practice, we have found a need for a broader conception of the research programme, one which includes affective and social issues within its conceptualization of cognition.

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The Influence of Model-Instruction on "Conception- and Misconception-Learning" in Biology and Physics

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Hochschule der Bundeswehr

An important approach to understanding structure, development and function of conceptions and misconceptions in thinking was achieved by developmental psychology, especially in the Geneva School (Piaget), which found out that the child passes through phases in his cognitive development in which his thinking functions less "logically" than rather "psycho-logically." Everything is connected according to clear but inadequate principles: animistic, artificialistic or finalistic. Psychology of thinking and personality found out, too, that men's thinking functions logically only under good conditions. In everyday life at least even in school you often find a "psycho-logical" thinking. That means that people organize daily experience according to their own idiosyncratic concepts (man as a scientist), which often work well in their familiar situations, but which fail when orientation in new areas is necessary.

In preparing students to solve unfamiliar problems, teachers should try to establish concepts in the students' cognitive structure which are good for a near and far transfer. As I mentioned above they, however, cannot trust on logic thinking alone, if they teach a new matter. They have to respect their own and the "psycho-logic" of the students. Here are some statements:

Einsiedler, a German psychologist, mentions:

> "The structures of matter which are found by logical analysis are not identical with the cognitive structures of the learner, since individual cognitive structures vary according to different assumptions and operations." 1/

Harvey, Hunt and Schroder describe cognitive structure under three dimensions: differentiation, discrimination and integration. Differentiation concerns the number of the main categories in a special field, discrimination the differentiation of these categories, and integration the rules in which the categories work together. The more categories and rules are based on misconceptions, the more idiosyncratic is the thinking. 2/

Ausubel (1974) emphasizes that psychological, in contrast to logical, meanings are always idiosyncratic (Ausubel S. 47).

As cognitive structure determines the meaning of experience (assimilative set), according to Ausubel, there would be a growing idiosyncratic development in the cognitive structure which, however, is compensated by common facts like language, structure of material and, last but not least, appropriate concepts which people learn at last.

However, you never know how idiosyncratic the thinking of others may be in a special field. That is a very important fact for therapy (Rogers) but even for school teaching, too (s. Ausubel and others).

Our own research in this field found out that, in spite of working with good teaching materials and adequate concepts, students often organized the subject matter in biology, physics or history by misconceptions. They learned only those facts which fitted to them. We called those concepts "competitive types," because they disturbed the planned organization of the subject matter.

An example:
In connection with the subject matter, "the meadow, an ecological system," sixth grade students should learn that the dandelion is a plant which often disturbs this system, because it covers much of the ground by its big rosette of leaves so that grass is displaced. Since it has a deep root, it can't be cut away simply; since each plant has a lot of "parachute fruits," it spreads out very far. So farmers call it a "grass thief."

In a test one week later, students described the dandelion as a plant which is dangerous to cattle and men because it has a poisonous liquid in its stalk, or they write that it is a jewelry for meadow and children because of its yellow blossoms. They did not remember the taught facts and explanations.

This kind of understanding was caused by conceptions which were already established in the learner's cognitive structure and linked with dandelions before instruction began: dandelion as a jewelry, dandelion as a poisonous plant. This linkage was so dominant that the planned instruction could not erase it. They became misconceptions when used to organize the taught facts. So this outcome confirms to Ausubel's or Novak's central idea that the most important thing in teaching is to find out what the learner already knows in regard to the subject matter.

But even if all facts of a subject matter are learned exactly, they may be organized by different concepts.

An example:
In physics, students should understand the function of a windshield wiper of a car. One student could see that the to and fro of the wiper is the transformation of a rotation. The axis of the electric motor revolves, but if you fix a point on this axis, this goes to and fro. So you have to transform this rotation by a mechanical construction and the wiper will do its work--to and fro. The student organized all information by the conception, "transformation of a rotation."

Another student could see how one mechanical element is connected with the next one and causes its moving so that finally the wiper works right, but he could not see the transformation process in the mechanical construction.

In a typical school test, both students may get the same score, but in wide transfer-tests the first student will be better because he understood the subject matter much more basically. He has established a more appropriate conception which enables him to solve equivalent problems in other technical fields.

What can a teacher do in order to establish the "rotation concept"?

First, he himself has to know that he can derive all mechanical elements of a wiper and their functions from the concept, "transformation of a rotation" to a "to-and-fro movement."

Then he perhaps can show with a lamp on the axis and a screen, that the light spot on the screen goes to and fro when the axis is circling. At least he may demonstrate how the mechanical elements transform the moving of the light point on the wiper.

So the whole instruction is focused in accordance to the basic concept, "transformation of a rotation movement."

This is the idea of our prototype-instruction, as we called it. We try to find a model or a prototype which can organize the dominant categories and facts of the subject matter and which represents a familiar organizing principle that is already or may be easily established in the student's cognitive structure.

Students know what a rotation is and they even know a to-and-fro movement. New for them is the combination: a rotation can be seen as a to-and-fro movement, too. This combination, however, can be established easily.

If you analyze free tests which show how students organize a subject matter (essay-form), you will find a short number of concepts which organize their experience in many fields.

So teachers:
- should try to activate the ones which fit the planned organization of the subject matter, and
- should know which facts of the subject matter are linked with "competitive type" conceptions which, if activated, will disturb or destroy the adequate organization of the subject matter.

In order to demonstrate the effects of appropriate or inappropriate use of conceptions in school learning, I shall present three projects: one from 1932 by E. Wohlfahrt concerning selection of high school graduates for universities, and two others from 1968 and 1974 concerning typical classroom research.

The first project was initiated in 1932 by the German government in order to select qualified students from high school graduates. This project became necessary because there were too many high school graduates who wanted to study, but much less capacity in the university, and no adequate jobs in industry--as today. 3/

This selection, however, was not delegated to the high schools--as in Germany today with very bad results--but to a central commission. It constructed a test with 14 sub-tests, 3 concerning science problems. In order to select those students whose thinking was versatile and to level differences among schools in "fact-knowing," the tests proved the use of conceptions in far transfer tasks.

For example:
"Imagine water would weigh only the 10th part instead of its real weight. What would happen?"

To answer this question, you must have an appropriate conception concerning swimming things, and you have to transfer your knowing to a science fiction situation.

Since this question is very unusual, you must select the adequate conception beyond those which have only a surface, but not a structural, connection to the problem. I shall give example for wrong answers to this question later.

There were three tests which proved the quality of conception use in science.

Instruction: Please answer the following four questions. Try to give an exact explanation.

First test
Analysis of familiar experience.

1. Why does it become cool in a closed room on a hot summer day, when you use a fan?
2. If I blow in smoldering coal, the glow becomes a light flame.
   If I blow a burning candle, the flame will die.
3. In a box there is a big number of bullets, 8 mm in diameter. One part is made of steel, one of brass. All are covered with nickel, so that they can't be discerned by view. You have to find the brass bullets most quickly. Show the different methods you can choose, and sign those which are quick and most simple.
4. The inside of a gun barrel is not drilled smooth, but has spiraled grooves. What is the advantage in comparison to a smooth drilled barrel which causes less resistance for the bullet?

Second Test
Application of physical conceptions in solving technical problems.

For instance:
Which technical conditions need to be realized so that a submarine can submerge, swim under water, and come up again to the surface?

Third Test
Application of science conceptions on science fiction problems.

1. See above the question concerning water.
2. Imagine that scientists have found a medicine which, once taken, extinguishes pain for the rest of the life. What would happen?

Wohlfahrt, who constructed this test and analyzed its results, published this project under the title, "Geist und Torheit auf Primanerbänken" (1934). That means "productive thinking and stupidity among high school graduates." He said (quotation): "It's not my fault when in my report stupidity is more dominant than examples of productive thinking." 4/

Those graduates were accepted from the University that demonstrated productive thinking in solving the above listed problems or in the terms of this seminar: that were able to use appropriate conceptions in solving unusual problems in regard to those which you will find in typical school textbooks.

Among 800 high school graduates in Saxony in 1933, 200 were successful. The rest produced inadequate results or in the terms of the seminar: They used conceptions which were inadequate to the given problems. So they became misconceptions and the elaborated solutions were wrong.

The following list shows appropriate and wrong answers.

First test: Analysis of familiar experience.

First task (fan):

Appropriate answer:
"Sweat evaporates; in connection with the wind of the fan, that causes evaporate-coldness."

Wrong answer:
1. "The fan sucks the warm air out of the room. Since the room is closed, warm air from outside cannot get in."
2. "The fan causes a high air pressure in the room, which pushes out the warm air."
3. "The fan neutralizes warm air."
4. "Hot air is dense. The fan thins the air. In high regions, air is thin, too, and there it is cool."

These answers demonstrate the effect of different misconceptions: the fan as a sucker, as a pusher, as a killer, as a thinner.

Second task (candle):

Appropriate result:
"In the case of the burning candle, the blow interrupts the connection between the burning gas and the wax. The hot gas, however, is necessary for the burning process, because it transforms the wax into gas which is necessary for the flame. Smoluering coal itself has heat enough to transform coal to gas. The blow doesn't cool it very much. So the process continues when the fresh air is added. It increases the process."

Wrong answer:
1. "The carbon dioxide, which you blow out, is necessary for burning coal, but it extinguishes candlelight."
2. "When I blow into smoldering coal, I give the warm temperature of my breath to the glow, which facilitates the burning."

Third task (brass bullets):

Appropriate result:
1. "Put them on a balance, brass is heavier."
2. "Throw them on the hard ground. Since steel is more elastic, steel bullets will jump higher."
3. "Prove all with a magnet. Brass is not magnetic."

Wrong answer:
1. "Make a fissure into the nickel with your fingernail and you shall see whether it is a brass bullet or not."
2. "Put the box in fire, the brass bullets will melt earlier."
3. "Beat with a hammer on the bullets. The brass bullets will deform."

Fourth task (gun):

Appropriate result:
"The spiraled barrel gives a momentum to the bullet. This will stabilize it on its path."

Wrong answer:
1. "The spiraled barrel gives a rifling to the bullet. So it drills through the air, which makes it faster."
2. "The spiraled barrel causes more friction. So the bullet gets hot and the gunpowder will explode."
3. "The spiraled barrel prevents a bullet from falling out of the rifle."
4. "If there would be no resistance, you would need less power to release the shot. So the bullet would not fly as far."

Second test: Application of physical conceptions in solving technical problems.

Task (submarine):

Appropriate result:
1. "The boat must have a hard hull against strong pressure."
2. "The boat must have electric engines."
3. "The boat must have tanks, which can be filled with water, so that it becomes heavier and which can be emptied by composed air."

Wrong answer:
"The boat must become heavier than the water. That you can do by a big magnet on the bottom of the boat. This will be stronger than the resistance of the water."

Third Test: Application of physical conception on science fiction problems.

First task (water:

Appropriate result:
1. "A boat had to be 10 times bigger but not heavier. So men would never have had boats because you can't construct such ones. The consequences: No trade over the Atlantic, no discovery and so on."
2. "Men would not be able to swim with his normal power."

Wrong answer:
1. "All measures would be wrong. If I fill up a vessel with one litre, so it would not be a litre."
2. "All other things would weigh 1/10th of their weight, too, because their weight is related to that of water."

Second task (medicine):

Appropriate results:
"Pain often is a symptom for illness. Without pain this could become worse before you see it. In this way, pain is a help."

Inappropriate results:
1. "Men would be happy and the doctors would have less to do."
2. "Without pain men would live longer since often their death is caused by pain."

How does the inappropriate result occur? If you are confronted with an unusual problem, you often behave like a man with closed eyes, who has to analyze an object by touching only. When he finds the first well known points, he figures out a picture in his mind, and this will lead to further touching and determine the meaning of the following touched things (assimilation set).

If his picture was appropriate, his analysis will be right; but if he figured it out too early, it may be wrong and his analysis will be inappropriate.

Very often you have the right picture in your mind, but you select another because:
- you don't wait until you have more information, or
- you are fooled by some well known items within the task which are, however, not those which lead you to structure of the problem.

For instance: the gun task: "spiral barrel"--spiral has a strong linkage to drill. If this meaning is established and related to a drill conception, other facts are assimilated or ignored. So the student gives a drill explanation: the barrel drills through the air and that makes it faster or it drills into the target which lets it go deeper.

This abuse of conceptions happened very often within the next two projects, too, which I shall present now. They concern research on the effect of model instruction in school learning. I already mentioned details of the biology project and the instruction strategy (see page 2). While explaining the experimental design and the results, I will add some more information about prototype instruction.

Second project: 5/

Subjects and design:

The subjects were sixth grade students of two classes of a primary school, about 30 students in each class. The experiment was conducted during regularly scheduled hours of a one-year biology course.

The students were taught by two instructional methods which differed in learning aid and sequencing. In one group a model, called a prototype, was constructed with the students in the first two of a six-lesson-period, which was the time for each subject matter. In this phase, important facts and the basic structure of a subject matter were already presented. So the prototype was not constructed separate to the subject matter; it was elaborated while explaining facts and their relations. In the next four lessons the main categories of the subject matter were differentiated and additional information was presented. At the end of the period the important facts and explanations were summarized.

In the other group no prototype was given. The same facts and structure of a subject matter were taught in a three-phase sequence (see the classic sequence of instruction in the tradition of Herbart in Germany).

First phase:
Introduction and presentation of concrete material; for instance, plants and little animals of a meadow, pictures and so on.

Second phase:
Systematic observation of plants and animals, elaboration of meaningful facts and relations, concerning the central concept "ecological system."

Third phase:
Summary (like in group two).

So in both groups the same facts and explanations were elaborated. In group two additionally a learning aid, the prototype, was used, and this was presented within the first phase.

This learning aid shall be explained in a more differentiated way now.

A prototype is a model with a twofold analogy. In relation to the subject matter, there is an analogy to the functioning of well known things (external), in relation to the cognitive structure it represents a basic familiar conception which children use in different areas (internal).

See, for example, the prototype to the subject matter, "the clover, a member of the ecological system, meadow".

Some details:
At the roots of clover, you find bacteria which produce nitrogen which is transformed to albumin partially. Among the plants of a meadow, only the clover has this bacteria at its roots. So it is a fertilizer to the other plants (nitrogen) and good food for the cattle (albumin).

What is its function in the system, "meadow"?

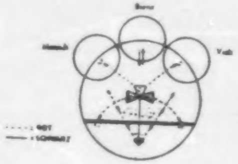
The clover centers nitrogen or albumin and gives it away to other members of the system. So "centering and spreading of something" is its function in this system.

This process children find in many everyday things, for instance, money-box, water reservoir, water sprayer, burning glass, compost heap, or in typical situations of an American football fight, and so on. So this is the first of the two analogies of the prototype (external). The second is an analogy to an operation concept in the cognitive structure which fits in different activities: classification and differentiation, pushing something together and spreading it, heap up and level something, crumple and stretch something, etc.

This model, the prototype, is the organizer of the subject matter, "the clover". All important facts and explanations concerning it can be elaborated on its base.

While it is constructed together with the students, it is transformed into a picture (see picture 1), so the students can store this central concept symbolically and iconically.

Picture 1. Clover



The prototype for the subject matter "dandelion" was named "resistant disturber" (see Picture 2, p. 37.

Results:
The results of the subject matter "the clover" and "the dandelion" shall be presented. The effects of the instructional methods were proved by open tests. There were no special questions, but the students were asked to write everything which is still new about the subject matter (essay test).

There were 5 tests up to six months after elaboration for each subject matter (next day, next week, one month, three months, six months). These were analyzed in different ways, for instance, style of writing, level of organization and content (facts and explanations that were reproduced). The results of the two last categories will be presented here.

Definition of the categories

1. Level of organization
   - High level: Most facts are organized by the prototype or a central misconception.
   - Low level: Most facts are connected "at random" or "deproche en proche" like Piaget would say--there is no "red line" in the subsequence of the facts, no explanations are reproduced.

   In this category quantity was not judged, but the quality of the organization of the essay. A high level was already indicated, if a little number of facts were organized strictly, a low level could be indicated, if many details were reproduced "at random."

2. Content

   For each reproduced fact or explanation that was taught, there were given points. If a fact was reproduced exactly: two points; if reproduced simply: one point; if an explanation was given as taught, that is, if the student explained corretly how things fit together, he received three additional points. The following tables show the results of the two classes in the second and fifth test.

Table 1

1. Level of organization (Only the main categories of the analysis are presented.)

Subject matter: Clover (f%)

Test	Second		Fifth	
Group	1	2	1	2
Level of Organization High:				
Conception....................	56	79	43	76
Misconception.................	35	18	43	17
Level of Organization Low:				
At Random.....................	8	3	6	6

Table 2

Subject matter: Dandelion (f%)

Test	Second		Fifth	
Group	1	2	1	2
Level of Organization High:				
Conception....................	19	91	41	74
Misconception.................	4[illegible]	6	24	6
Level of Organization Low:				
At Random.....................	36	3	32	16

The difference among the two groups concerning the subject matter "dandelion" is much greater. Since the dandelion is a flower which is used in many ways by children, here the misconception rate is very high (see example above). The prototypical organization of the subject matter reduces the influence of misconceptions: 91% organized the facts as taught; 75 even half a year later.

The results of the clover test demonstrate that even in group one the subject matter was taught in regard to the same structure as in group two but without using a prototype: 56% organized the facts as taught, still 43% half a year later.

One important change you can see in group one concerning dandelion, first line: 19% in the second test, 41% after six months. Where does this increase come from? As mentioned above, both subject matters were taught in connection with the subject matter, "the meadow an ecological system," which was taught in a three-month period. The dandelion was the second subject matter in this period (first "grasses"). At the end of the period even in group 1, the frame structure of the whole subject matter was more pregnant (system) than at the beginning. So more students saw dandelion in regard to this frame structure and reproduced more appropriate facts.

Which misconceptions were used? See Table 3.

Table 3

Clover (f%)

Test	Second		Fifth	
Group	1	2	1	2
Misconception				
Worthy and useful	29	12	43	14
Worthy	3	3	0	0
Good and bad plants	3	3	0	3
Total	35	18	43	17

Table 4

Dandelion (f%)

Test	Second		Fifth	
Group	1	2	1	2
Misconception				
Surviver	19	0	9	3
Good and bad plants	12	6	9	5
Spreader	6	0	3	0
Disturber	3	0	3	0
Jewelry	5	0	0	0
Total	45	6	24	8

2. Content

The following table shows the results of content analysis.

Table 5

	Clover (max.: 30 points)			Dandelion (max.: 36 points)		
Group	1	2	stat. test[1]	1	2	stat. test
Test						
I	11.8[2]	15.1	< 5	11.0	17.9	< 0.1
II	10.1	15.2	<0.1	11.1	18.3	< 1
III	8.5	11.0	n.s.	9.2	17.5	<0.1
IV	6.9	9.8	< 5	8.0	16.2	< 1
V	6.4	11.1	< 1	8.4	13.1	< 1

1. Median-test (Mood); U-test (Mann-Whitney)
2. mean

Group two is more successful in 9 out of 10 cases.

The following table shows the relation between 'level of organization' and 'content.

Table 6

CLOVER

Test				
Category	Level of Organization	Content	Level of Organization	Content
Group 1	Conc. 56 Misc. 35 } % At r. 8	10.1	43 43 6	6.4
2	Conc. 79 Misc. 18 } % At r. 3	15.2	76 17 6	11.1
DANDELION				
1	Conc. 19 Misc. 36 } % At r. 36	11.1	41 24 32	8.4
2	Conc. 91 Misc. 6 } % At r. 3	18.3	74 6 16	13.1

"Level of organization" and "Content" correlate. If the basic concept of a subject matter is presented as a prototype, students organize the essay more systematically and reproduce more facts and explanations as in case of teaching the subject matter emphasizing the same structure but not figuring out the organizer itself. The score of misconception is high, the content score low: misconceptions organize less of the taught information but some which were not given, but fit the misconception and were already stored in the student's cognitive structure.

Mention: Both groups had nearly equal scores in IQ tests (Group 1--107; Group 2--102) and in other subjects such as math, geography, language, etc.

Interviews with students of group 2 show why the symbolic and iconic representation of the prototype made it so profitable.

Students mentioned:

"If I know the picture, I can follow better. I know how the things fit together."

"When I have painted the picture, I look at it. Then I can write; there is everything summarized, and that you can see. While writing I sometimes look at the picture again."

"The picture tells me what I have to write."

"First I think what the picture looks like. Then I paint it. Then I know how to start. While writing, I remember many more facts."

"There I can see in which way the things fit together. I can see what you explain."

Among the 13 different subject matters which were taught in this project and analyzed, the same results occurred. Among 54 comparisons concerning content, 46 are significant on the 5% level or better in favor of group 2, in no case in favor of group 1.

Third project: 6/

The third project concerns the subject matter, physics, and was conducted by Gunter Heisterkamp in 1968 and 69. The design is similar to the second one. Sixty-six 10-year-old students of an elementary school were divided at random in two classes at the beginning of a normal school term. The subject matter was "mechanics of liquid and gaseous things." This course was the first in physics for the students. The subject matter were everyday phenomena like water pipe (aqueduct), cans, air lock for drains, fountain, dam, mason jar, air pump, balloon, suction-pipe, pulleys, etc.

One group was instructed in the traditional way as I mentioned above (3-phase), the second group was instructed prototypically. The basic concepts of the different technical phenomena are:

1. Balance or unbalance of physical pressure, which work against each other or in opposite directions. It was prototypically presented and transformed into a picture (see picture 3, page 38). The basic form was changed according to the different applications that were taught.
2. Dissolving and condensing of things; dissolving leads to a gas, condensing finally to a solid status. The iconic transformation shows picture 4 (see page 38).

The effect of instruction was tested in three forms.

1. Completion of pictures (see picture 5, page 38).
2. Questions: For instance,

   "Why can a diver only dive up to 10 meters without a diving-suit?"

   "Why does a balloon filled with gas burst if it climbs up very high in the sky?"

   "Why is a dam of a storage lake thicker on the bottom than on the top?"

3. Essay:

For instance, "What do you know about a capillary tube?"

The answers to test two and three were scored with two points when exactly right (EX), one point when partially right (P), or not exactly right (N.EX); no point when the answer was wrong. (S. 102)

The next table (S. 104) shows the results of the two groups.

Table 7

Group	A	C	A in %	C in %
EX	218	452	21	42.5
N.EX	75	112	7	10.5
P	245	206	23	19.0
Mistake	514	293	49	28.0
Total	1052	1063	100	100.0

Group C is better. So this project confirms the results of the last one.

In this seminar the wrong answers are interesting. Heisterkamp found five different forms under which three are relevant for our questions. Inappropriate transfer of well-known concepts that means misconception use. Table 8 shows the different forms of wrong answers.

Table 8

Group	A	C
Type of Mistake		
Misconceptions.................	218	98
Substantializing............... ("Aristotelian" explantion)	120	34
Process-description............	71	16
Total.............	409	148

Explanation of the three forms:

Misconception: "The balloon bursts because it has no more oxygen."

Substantializing: This is even a form of misconception like Piaget found in the child development (s. above animistic concepts).

An example:
Answer to the diver question: "The pressure is going into the inner ear."

Answer to the question concerning a dam: "The pressure on the ground of the lake is more deep than above."

Pressure is not own substance. It is always a product of different influences. So it cannot go into something, nor be deep or high. So substantializing is a specific form of a misconception.

Process-description: The student gives a description of what has been done in the classroom.

For example, question: "How can you suck water with a tube?"

Answer: "We took a glass with water and a tube. Then everybody was allowed to suck. All were not successful. But if you sucked strong enough, then the water came out of the tube like a little fountain."

In the last example, the student is not able to organize the subject matter by a central conception or misconception. So he describes the process.

Summary of projects 2 and 3

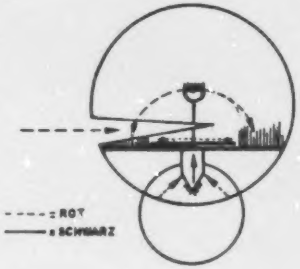
If you want to establish appropriate conceptions in the heads of students on the basis of everyday experience and if you demonstrate the subject matter by interesting experiments, you have to consider the psycho-logic of the students, that is, their central concepts with which they explain phenomena (see Piaget).

If there is a subject matter which has a great affinity to one of these conceptions and if that would become a misconception if used to explain the subject matter, you have to equip the students with an appropriate organizer which is so powerful that the misconception is cancelled.

If you do not do this, in spite of emphasizing good teaching, even students in the upper classes in high school will not be able to transfer conceptions learned in the classroom on everyday experiences.

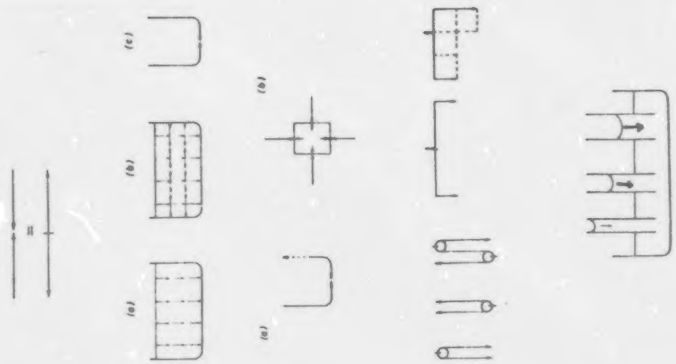
NOTES:
1. Einsiedler, W. Lehrstrategien und Lernerfolg, 1976, p. 69.
2. Seiler, B. (ed.), Kognitive Strukturiertheit, 1973.
3. Wohlfahrt, E., Geist und Torheit auf Primanerbänken, 1934.
5. Ennenbach, W., Prototypen des Lernens und Unterrichtens, 1970.
6. Heisterkamp, G., Psychologische Prinzipien des Mathematick- und des Physikunterrichts, 1974.

Picture 2:



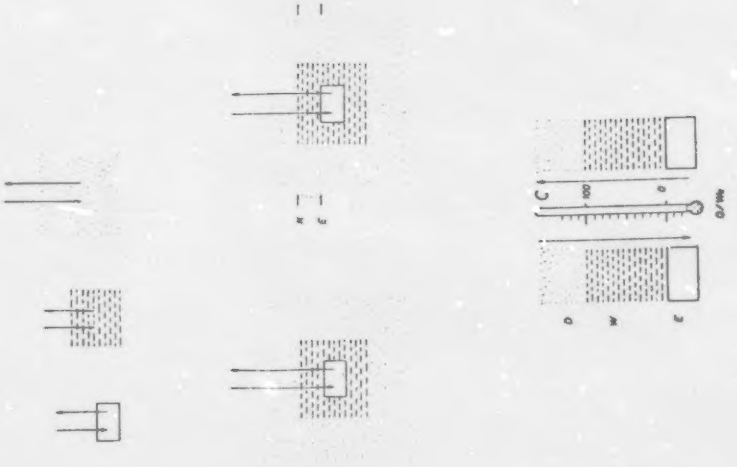
Picture 3:

HEISTERKAMP 1974



Picture 4:

HEISTERKAMP 1974


K
E
C
100
0
0/100
D
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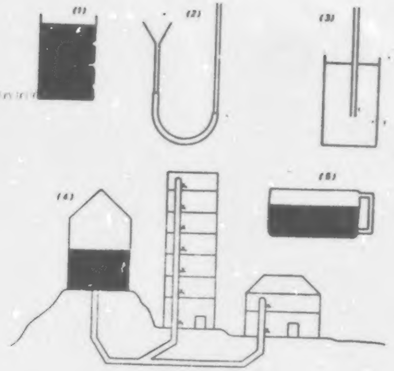
Picture 5:

HEISTERKAMP 1974



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STUDENT FRAMEWORKS AND CLASSROOM INSTRUCTION*

Introduction

Considerable effort has been expended over the previous five years to identify and represent the type of ideas or beliefs that students have constructed prior to formal instruction in a school setting. It seems safe to conclude that this effort has not been unrewarded, as there now exist many accounts of students' common-sense or spontaneous knowledge (Strauss, 1981) in the education literature. (See Driver and Easley, 1978; Driver and Erickson, 1983; Gilbert and Watts, 1983; and West and Pines, 1983; for reviews of this work). While there are still many differences in the methodological and theoretical prescriptions used by researchers, few now deny that most students have constructed at least some implicit ideas about many of the concepts which are presented in the school curriculum. The relationship between students' spontaneous concepts and classroom instruction has remained, however, at the level of an important assumption or premise in the arguments justifying research programs on student knowledge. See Figure 1 for a version of this argument as reconstructed by Driver and Erickson (1983).

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Figure 1 about here

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While there has been some theorizing about the nature of this relationship between student knowledge and instruction (Easley, 1980, 1982; Gilbert, Osborne and Fensham, 1982; Hawkins, 1978; Pines, 1982; Posner, 1981), much of

the recent work seems to have been directed towards an examination of the stability of this type of student knowledge when exposed to specific teaching strategies (Hewson, P., 1981; Hewson, M. and Hewson, P. 1981; Posner, Strike, Hewson and Gertzog, 1982; Nussbaum and Novick, 1981; Stavy and Berkovitz, 1979; and the recent 1983 AERA Symposium on Stability and Change). The primary purpose of this paper will be to consider in somewhat broader relief, a number of issues pertaining to the interaction between students' existing knowledge and instruction. This will be done in the context of describing the framework for a research programme which we have initiated and discussing some preliminary results from several classroom-based studies which are currently in progress.

The Research Programme

The broad phases and constituent components of this research programme are outlined in Figure 2. During the previous five years we have focused upon

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Figure 2 about here

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ways of identifying and representing student knowledge as depicted by phase one of programme. A summary of this earlier work on student frameworks is provided in Appendix 1. Evidence from this work, plus the numerous other studies which have been conducted in the area of student common-sense knowledge, have led us to the conclusion that this knowledge is pervasive and potentially significant from an instructional vantage point, and hence we have shifted

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*Late arrival, out of sequence.

some of our attention to phase II activities. In so doing, we are not claiming that all of the problems associated with the identification and representation of student frameworks have been addressed or solved.

Rather, we are simply indicating that sufficient evidence is available to warrant a shift in priorities to the next phase of the programme. This phase presents us with a series of tasks of even greater complexity than those encountered in the first phase.

Classroom-Oriented Studies

Just as a researcher inquiring into students' conceptual commitments is faced with a wide repetoire of methodological and theoretical perspectives, so is a researcher interested in examining the complexities of a classroom environment. We have opted for a technique, not dissimilar in many respects to that we have used in studying student frameworks, which Easley (1982) has characterized as a type of naturalistic case study. Easley argues that it is through these types of naturalistic studies that we can best conduct "the search for mechanisms that could fruitfully direct our efforts to quantitative laws and experiments." (Easley, 1982, p. 192). Although the two studies that will be used to illustrate our approach differ in terms of the content being taught and the grade levels which were involved, the following three general questions were addressed by both studies:

(1) What are the common-sense beliefs held by specific students about a given topic area prior to formal instruction?
  - practical methods of identifying these beliefs in classroom context.

(2) Is there any visible evidence of interaction between students' common-sense beliefs and instruction?
  - was teacher aware of students prior knowledge?
  - did text materials consider that students may posses alternative ideas?
  - was there any evidence of differential responses to instruction based upon students prior knowledge?

(3) Are there any changes in the students' common-sense beliefs as a result of instruction?

Haggerty's Case Study of Heat and Temperature in a Grade Nine Classroom

Prior to commencing the instructional unit, all students responded to a group-administered questionnaire, developed by Shayer (1981); they were subsequently interviewed by Haggerty, who asked them to explain, clarify or expand their responses to the questionnaire. Using the students' responses to this questionnaire and interview she was able to determine the types and the range of common-sense beliefs held by the students before instruction commenced.

Since one of the primary objectives of this study was to obtain some insight and some direct evidence into the role played by students' common-sense knowledge in a normal classroom setting, Haggerty adopted a relatively non-obtrusive stance in gathering the classroom data for her study. She was interested in two interrelated aspects of the classroom environment: first, how does the teacher make provision for student learning in terms of the various instructional activities which are planned and implemented and second, how do students 'make sense' of these routine instructional activities. In order to collect the necessary data to respond to the above questions, all large group and a number of small group discussions were tape-recorded for the duration of the three week unit. In addition all the written work of a selected group of eight students was collected, marked and photo-copied for subsequent analysis.

After completion of the unit all students were given a teacher-made achievement test and the Shayer questionnaire once again. These measures, along with the classroom-based data, were used to obtain evidence on whether the students altered their conceptions of heat and temperature to any extent as a result of their exposure to this type of laboratory oriented instruction.

Tentative Results

Prior to instruction most of the students discussed matter in terms of particles and many seemed to be aware that these particles were involved in phenomena such as heat transfer and expansion effects. About half of the students stated that when matter is heated the particles tend to move faster. It was clear, however, that a kinetic theory was not consolidated in these students as many of them on subsequent questions described heat in terms of: a particle, its capability to move between the particles of matter, or its tendency to push particles of matter.

To try and capture some aspects of the many different kinds of interactions between the student, the teacher and the materials which occurred during the instruction, Haggerty prepared a 'conceptual biography' for each of the eight target students. These biographies included a description of the students' framework at the beginning and the end of the instruction unit (as was determined by the pre and post tests and interviews); but more importantly, it contained a description of any development or modifications in their initial framework in response to the various instructional activities in which they were engaged. This descriptive material comes from students' verbal responses in class, written responses to text book and laboratory assignments, and informal conversations with the investigator. An attempt will also be made to see whether the modifications can be accounted for in terms of the model of conceptual change proposed by Posner, Strike, Hewson and Gertzog (1982).

While the analysis is not yet complete it seems apparent that very little opportunity was provided by the teacher for the students to either articulate their beliefs in any systematic way or to seriously question the kinetic framework which was being presented in a methodical and lock-step fashion. The following brief excerpt illustrates the nature of a typical interchange. This exchange occurred following a demonstration with a ball and ring apparatus. With this apparatus the teacher illustrated that a ball heated in a bunsen burner would not pass through a ring. The ball was then immersed in cold water accompanied by a sizzling sound and ri[illegible] steam.

Teacher: It was hot before, now it's cold. Where did the heat go?
Bob: It evaporated.
Teacher: Susan?

This very short exchange illustrates several interesting characteristics of the classroom environment which were operative during the heat unit. First, the wording of the question is very suggestive of a "fluid" framework for heat (which tends to characterize much of our common language) and so it should not be surprising that Bob offered evaporation as a plausible mechanism. However, the teacher not only failed to recognize the inherent logic in Bob's response, he ignored it entirely and proceeded on to another student, hoping for an answer closer to the one in his own mind. This sort of exchange effectively communicates the message to students that 'the name of the game' is to try and decipher and use the framework presented by the text and the teacher. In Appendix II a more extended discussion, from a different teacher's classroom, is provided which portrays the persistence of some students' ideas even though they are directly confronted and attempts are made to refute them with evidence.

Analysis of the post-instructional questionnaire revealed some shifts in specific beliefs (in particular those which were emphasized by the teacher and the text). But perhaps the most salient finding to date is that even though some students can repeat teachers and text messages almost verbatim, (e.g. "when matter is heated the mechanical energy of the particles increase") in different sections of the questionnaire many of them write about: the particles of matter expanding when they are heated, the spaces between the particles of matter expanding, or describing heat itself as a type of particle.

In summary, with part of the analysis completed, it would seem that instruction did indeed influence some students to make kinetic-like responses on the post-instructional questionnaire, but nonetheless many of their common-sense beliefs about heat either remained or were in a state of co-existence with kinetic-like responses after the completion of the unit.

Snively's Study on Children's Orientations to the Seashore

In contrast to most of the existing work on student frameworks, Snively felt it was necessary to expand the notion of a framework to include both beliefs, and values which a child may have when thinking about the seashore. Hence she selected as her unit of analysis an "orientation" which was defined as "a tendency for an individual, a group or a culture to understand and experience the world through a preferred interpretative framework, which embodies a coherent set of implicit beliefs, perspectives and values." In order to try and reveal these more affective and tacit aspects of cognitive functioning than is usually obtained from traditional approaches, Snively adopted a metaphorical interviewing technique which has been developed and used by Beck (1980, 1981) in an anthropological setting.

Overview of a Metaphorical Interview

There are several different formats which are used to elicit students' responses; most of these ask the students to select from a list provided by the interviewer one or more metaphors which best describe their thoughts/ideas about an object, event or relationship at the seashore. The most critical aspect of the interview is the explanation given by the student as to why that particular metaphor best describes the object or event of interest to the investigator. See Figure 3 for examples of some of these different formats and lists of metaphors.

Figure 3 about here

While some attempts have been made to use production formats (i.e., the students are asked to spontaneously generate their own metaphors for a given phenomena), they do not tend to be as useful as formats which provide the metaphor. This is because providing their own metaphor is a difficult task for most students and they tend to use 'cliched' metaphors which we think may not represent their own ideas or thinking.

The determination of a child's preferred orientation then, is based upon the explanations they offer as to why the metaphor which they selected best characterizes their thinking about a given event or organism. Among some children these orientations appeared to be quite stable over different events and organisms and even over different task formats. An example of a series of responses from one child over different task stimuli and formats is given below. This example was judged to represent a strong 'utilitarian orientation'. (See Figure 3 for explanation of the task formats.)

Task 1: "The seashore is a farm." (Why?) "It's got lots of animals. You look after them, feed them, raise them to be big; sell them to people for meat."

Task 2: "A clam is a pot-luck dinner." (Why?) "When you have a potlatch feast they make clam soup."

Task 3: "I would be an edible crab." (Why?) "Because you could eat them. Boil them and eat them. And you could put them in the aquarium."

Task 4: "I am to the seashore as a driver is to a car." (Why?) "I am the driver. The seashore is the car. A driver drives a car. I drive a seiner boat and go fishing."

These are simply a very brief excerpt of a few selected responses from one child illustrating a very strong utilitarian orientation which seems to pervade the thoughts of this particular native Indian child. They also illustrate another very important aspect of children's conceptions of the seashore as revealed by metaphoric interviews -- that is the importance of the two-sided nature of their thinking. On the one hand we see extensive use of mode of specific, sensory-based experiences (eg. the many references made to going out in his father's fishing boat) while on the other we see children using images embedded in a specific social or cultural context (eg. the reference to a potlatch).

The complete set of orientations, which were identified in earlier pilot studies, and in the final study, were: aesthethic, health and safety, scientific, spiritual, recreatioaal and utilitarian. In all cases there was some mixing of these orientations, depending upon the context of the interview questions, however, some students maintained one or two strong orientations across all task formats and questions.

The Instructional Setting

The grade six class used for the study was located in a small, coastal village and over 50% of the class were Native Indians. Commerical fishing was the main source of income for both Native and non-Native families. On the basis of the pre-instructional interviews six students were selected for in-depth monitoring during the instructional unit. Selection of these students was made on the basis of whether they could be identified as possessing one or more distinguishing orientations.

From an instructional point of view the lessons were primarily aimed at teaching ecological concepts centered around seashore relationships: for example, birth, growth, tidal cycle, predation, food chain, energy, community, zonation and system. Another underlying aim, however, was to increase the students' awareness of alternate orientations toward the seashore through the use of a variety of instructional metaphors. Thus while the unit was being presented Snively paid very close attention to: the types of spontaneous metaphors the students used in the course of their small-group or large group discussion, the way in which they received or interpreted the instructional metaphors which were formally introduced by the teacher and finally whether a student's predominant orientation toward the seashore prior to the unit influenced in any way the manner in which they 'responded to' and 'built upon' the instructional metaphors. To illustrate these latter two points she was interested in determining if a student with a high aesthetic orientation would accept and use 'the seashore is a necklace' as a type of metaphorical bridge for the concept of food chain or likewise, if the notion of 'a barnacle is a fisherman' would serve this cognitive bridging function for a utilitarian student learning the concepts of predator and prey.

Summary of Tentative Results

1. The interviews using choice and explanation of preferred metaphors worked very effectively and enabled the researcher to identify several different orientations used by the students (eg., utilitarian, aesthetic, spiritual, recreational, scientific, health and safety). While some students tended to use one predominant orientation, others used several orientations depending upon the context of the interview questions.

2. Only a small proportion of students used accepted scientific ideas in the pre-instructional interviews. Also, there was a great diversity in terms of the number and the veracity of beliefs about the seashore, its various organisms and the relationships among them.

3. Preliminary evidence suggests a reasonably strong interaction for some students between the type of orientation held, the types of metaphors preferred in the metaphoric interviews, the types of metaphors generated during instruction and the types of metaphors preferred as instructional metaphors.

4. A large proportion of students used accepted scientific ideas in the post-instructional interviews. It would appear that the primary aim of increasing their useage of a scientific orientation (that is to become aware of the abstract relationships and concepts associated with beach ecology) was obtained for most students.

5. While the students acquired many new beliefs about the seashore, their composite orientations tended not to undergo much change. Most student still offered explanations which were similar to the orientations they possessed before the unit began.

6. Many of the science concepts they learned during the unit and also the orientations used were still in evidence in interviews six months after the completion of the unit.

Some Issues of Classroom-Based Research

Although we have just initiated work at the classroom level in our project, already a number of practical as well as methodological/theoretical issues have emerged which would seem to be characteristic of most naturalisti classroom studies.

One of the first practical problems to be faced by a propsective researcher is that of finding a suitable and co-operative classroom setting; that is, the problem of gaining entry which has been discussed at some length in the literature (for recent discussions see Rist, 1982 and Easley, 1982). Since the institutional constraints and requirements are often unique to the school system I will not elaborate on the methods we used. But the degree of cooperation does seem to be related to several practical factors.

The first of these factors is the degree of obtrusiveness in the classroom. This can take the form of the technology required for data collection (ranging from lights and video-cameras to a non-participant observer taking field notes). Or, this obtrusion can also be expressed in terms of the degree of teacher involvement in the study. For example, the heat study was essentially a 'status study' requiring very little deviation from regular teaching routines and materials; whereas in the seashore study the researcher was a more active participant and assisted the teacher in planning many of the teaching activities. The extreme end of an 'involvement' continuum would be a situation which has been described as "teacher as researcher" (Foster and Nixon, 1978) where the traditional roles between the teacher and the researcher become blurred.

Another practical factor involved in soliciting cooperation is the issue of pay-off for the teacher. Commitment to some vague notion of 'professional responsibility' becomes very hollow in the absence of any form of perceived gains in terms of intellectual stimulation, new teaching materials, some release time or other compensations. With ever increasing demands on their time and their classrooms, teachers are rightly asking prospective researchers to justify their access to classrooms in terms of some form of cost-benefit calculus.

Turning to some more theoretically-based issues, the primary one for us has centered around a clear delineation and rationale for the problem statement. It is necessary to provide an acceptable response to the following three questions: What exactly is it that you want to study? Why is it important? and How do you intend to do it? A suitable reply to all of these questions requires embedding the study either in an appropriate theoretical framework or in a body of established practice. At this point in time we have been content to remain very much at a descriptive level and produce a limited set of naturistic case studies which essentially mirror the natural history-type studies of students that we carried out in phase 1 of our program.

Other issues which have emerged in discussion but not in practice (until we reach the phase of producing teaching materials and strategies) are those which center around the type of teaching strategies appropriate for a 'constructivist approach to teaching' and those which raise that most difficult question of 'What ought to be the goals of a constructivist science curriculum?'

I will comment briefly on the issue of suitable teaching strategies since it did impinge on our studies in several ways. The most obvious of these is the need for some technique to assess student beliefs either before or during an instructional unit. It is obvious that teachers will not be afforded the opportunity that we had to interview each student. A response that we had earlier proposed was to develop large-group interviews with the teacher displaying and demonstrating the task questions at the front of the room and the students responding directly on their own questionnaire (e.g.: Erickson, 1980; and Aguirre, 1981). This format is similar in some respects to other diagnosis-remediation sequences used in subject areas like reading and mathematics and draws heavily upon a metaphor from medical practice. In addition to an extreme uneasiness about implicitly conceptualizing children's common-sense knowledge as a type of 'illness', I am also concerned about any attempts to categorize this knowledge in such a way that specific treatments (teaching strategies) could subsequently be prescribed after diagnosis. This latter concern stems in part from the vision of a system where the 'student as patient' becomes locked into certain instructional sequences as a result of some diagnostic report. While we have not begun a sustained or systematic approach to the third and fourth phases of the project yet, our preference at the moment for addressing some of these issues is to first make teachers aware of the issue of student common-sense knowledge (using as many examples embedded in typical classroom contexts as possible). A second step will be to illustrate a variety of teaching maneuvers which they might employ both to encourage students to make their ideas more visible and explicit (see - Easley and Zwoyer (1975) for a discussion of some of these techniques) and once identified, to work with these ideas toward achieving the desired instructional aims for that unit.

This discussion leads to the last issue that I wish to raise briefly here: the perennial question of the goals of science education. One can argue that a constructivist approach to teaching could be implemented with any set of goals or in any subject area. That is, it speaks mainly to the method of teaching a subject rather than specifying what is to be taught. While there is a certain ring of truth to such an argument, I strongly suspect that there are certain goal specifications which would be more compatible with a constructivist approach. We can posit that one of the defining characteristics of this approach is to assist students in developing a set of meaningful ideas of the world about them which are more convincing and powerful than the common-sense ones they currently hold.

In a recent review paper of this research area West, Pines and Sutton (1983) lay out a provocative model which argues that this development can occur in either a "revolutionary" or an "evolutionary" mode -- depending upon the nature of the content being presented and the extent of the students' prior knowledge of the content area. This model may provide some interesting and useful insights into how one best organizes instruction, but the overall aim of increasing the scope and effectiveness of students' interpretative frameworks remains the same.

The implications of a constructivist approach, then, would suggest that while we will endeavour to structure instructional events in such a way that students will be persuaded that there are more fruitful ways of explaining their experiences, we must also recognize that a student may 'opt' for what we consider to be a less powerful framework (such as a fluid view of heat). As Osborne, Bell and Gilbert (1983) convincingly argue, there exists a large gap between children's science and scientists' science; a gap that most of us know is not easily bridged by most students. The critical question becomes: are we willing to submit that successful teaching may have occurred even if the student does not produce or possibly even understand the 'correct explanations' as supplied by the current scientific framework? To do so would mean that a considerable shift in one traditional goal of science teaching has taken place. In such a scenario the important aims have been shifted to the importance of students reflecting on their own knowledge and in the light of other alternatives (presumably one of which would be the current scientific framework) making and defending a choice to either continue with

their original common-sense set of beliefs -- or perhaps even elaborating a more sophisticated version. This scenario would imply that the students have come to appreciate the nature of scientific knowledge -- the role that theories play in accounting for experience, the way in which theories may be altered and some understanding of what constitutes a satisfactory rationale for a theory. Given appropriate materials, this approach may well prove to be more attuned to the development of "curriculum emphases" (Roberts, 1982) which have traditionally competed with the dominant science as "correct explanations". For example, the importance of students' personal knowledge, which is based upon some measure of reasoned reflection, would seem to be more compatible with the emphases that Roberts (1982) identifies as: science as a means of "everyday coping"; "science, technology and decisions" (commonly referred to as science and society); or the "self as explainer" emphasis.

If we were to look seriously at the legitimacy of these other goal orientations, or emphases (which currently seems to be the case with the science and society orientation) then the type of genuine understanding of the relationship between theory and phenomena implied by a constructivist approach may indeed lead to a situation where students will "know less so that they can learn more."*

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* A proposal made in a recent talk by Richard West (University of Sussex, Secondary Schools Project, England), during a meeting at the Canadian Society for the Study of Education.

FIGURE 1

Implicit Argument Used to Justify Research
Programs on Students Existing Beliefs
(from Driver and Erickson, 1983)

Empirical Premise One: Many students have constructed from previous physical and linguistic experience frameworks which can be used to interpret some of the natural phenomena which they study formally in school science classes;

Empirical Premise Two: These student frameworks often result in conceptual confusion as they lead to different predictions and explanations from those frameworks sanctioned by school science;

Empirical Premise Three: Well-planned instruction employing teaching strategies which take account of student frameworks will result in the development of frameworks that conform more closely to school science.

Value Premise One: One should conduct research which will lead to a better understanding of school science by students.

Conclusion: We ought to engage in research endeavours which will uncover student frameworks, investigate the ways they interact with instructional experiences and utilize this knowledge in the development of teaching programmes.

FIGURE 2

Overview of Framework for U.B.C. Research Program

PHASE	MAJOR RESEARCH TASKS	UNRESOLVED QUESTIONS/ISSUES
1	Identification of Student Frameworks	- What constitutes a framework? - Are frameworks content-dependent - What is the best unit of analysis
2	Teachers' perceptions of student difficulties Analysis of classroom interactions	- Are teachers aware of student frameworks? - How do student frameworks interact with instruction? - How stable are student frameworks?
3	Development of Teaching Materials and Strategies	- What are the desired goals of Science Education? - Can group-administered assessment techniques be developed? - What major changes in teaching styles and strategies are required?
4	Implementation of Teaching Materials and Strategies	- Do the changes really make a difference?

Format 2. The Children's Over-all Metaphors for the Animals, Objects and Events at the Seashore

In this interview the respondent was asked to decide, for example, which of five pre-selected metaphors (thumb tack, fisherman, song, house, rock) best describes a particular organism (barnacle). In addition, the respondent was asked to explain "WHY" a particular metaphor was chosen.

1. Barnacle
_____ thumb tack
_____ fisherman
_____ song
_____ house
_____ rock

2. Seagull
_____ spear
_____ robber
_____ pearl
_____ janitor
_____ dance

3. Seaweed
_____ garden
_____ banana peel
_____ curtain
_____ forest
_____ patchwork quilt

4. Crab
_____ garbage collector
_____ pair of pliars
_____ mobile house
_____ feast
_____ robot

5. Cobblestone
_____ umbrella
_____ hairbrush
_____ community
_____ totem pole
_____ hotel

6. Tidal pool
_____ painting
_____ store
_____ town
_____ dance
_____ war

7. Sea Star
_____ spaceship
_____ can opener
_____ flower
_____ burglar
_____ jewel

8. Tide
_____ song
_____ map
_____ bowling ball
_____ legend
_____ gift

9. Sun
_____ jewel
_____ furnace
_____ gift
_____ lamp
_____ factory

10. Mud
_____ pillow
_____ tunnel
_____ piano
_____ put-luck dinner
_____ city

11. Clam
_____ dance
_____ vacuum cleaner
_____ legend
_____ potlatch
_____ necklace

12. Sea Water
_____ diamond
_____ soup
_____ theatre
_____ factory
_____ dance

13. Sea Anemone
_____ garden
_____ flower
_____ mouse-trap
_____ dress
_____ person

14. Sand
_____ graveyard
_____ sandcastle
_____ theatre
_____ mattress
_____ bullets

15. Sea Urchin
_____ pin cushion
_____ sun burst
_____ spaceship
_____ lawn mower
_____ farmer

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FIGURE 3

Different Formats Used in the Metaphoric Interview

Format 1. The Children's Over-all Metaphors for the Seashore

For each of the four sets of metaphoric images (below) the respondent was asked to list his or her first, second, third, fourth and fifth choices. Then, for the first three choices, the respondent was asked to explain "WHY" a particular metaphor was chosen. The respondent was also asked "WHY" a particular metaphor was chosen last.

Sets of Metaphoric Images

(a) _____ factory
(b) _____ painting
(c) _____ house
(d) _____ battleground
(e) _____ legend
(f) _____ gift

(g) _____ farm
(h) _____ dance
(i) _____ graveyard
(j) _____ blackberry bush
(k) _____ totem pole
(l) _____ hotel

(m) _____ pot-luck dinner
(n) _____ necklace
(o) _____ town
(p) _____ pin cushion
(q) _____ playground
(r) _____ song

(s) _____ cannery
(t) _____ patchwork quilt
(u) _____ family
(v) _____ jewel
(w) _____ spaceship
(x) _____ garden

Format 3. IF YOU WERE A . . . .

1. If you were a crab ([illegible]), would you most like to be a:
   purple shore crab [illegible] edible crab
2. If you were a sea star ([illegible]), would you most like to be a:
   sunflower star [illegible] purple star
3. If you were a rock (t' [illegible]), would you most like to be a:
   boulder sand grain polished beach pebble
4. If you were a bird, would you most like to be a:
   bald eagle (kwikw) raven (g̲wa'wina) seagull (t' sikẁi)
5. If you were a fish ([illegible]), would you most like to be a:
   sculpin (tak'astan) (bullhead) blenny (tł̲amkw) (eel) salmon (kut̲ala)
6. If you were a type of seashore, would you most like to be a:
   rocky shore cobblestone beach sandy beach mud flat
7. If you were the weather, would you most like to be a:
   sunny day [illegible] day rainy day
8. If you were a mammal, would you most like to be a:
   seal ([illegible] wat) sea lion (t'[illegible]'an) killer whale (max̲'inux̲)
9. If you were the wind, would you most like to be a:
   windy day gentle breeze hurricane
10. If you were the tide, would you most like to be a:
   low tide high tide ebb tide
11. If you were one of the following, would you most like to be a:
   sail boat ferry boat fishing boat
12. If you were anything you wanted to be at the seashore, what would you most like to be? ____________ Why? ____________
13. If a [illegible] were [illegible] of the following animals, which one would it be: killer whale, bald eagle, raven, salmon, barnacle, crab, sea star, clam. Why? ______________________

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Format 4. The Student's Own Metaphorical Relationship to the Seashore

For this last type of interview the respondent was asked to decide which of three pre-selected metaphors was best suited to symbolize his or her own relationship to the seashore. The metaphors were chosen to represent contrasting relationships (driver and car) or (mechanic and car) or (passenger and car). In addition, the respondent was asked to indicate directionality. If the respondent's relationship to the seashore was like a driver to a car, which element of the dyad could the respondent call the driver and which the car, and "WHY?" The answer was a forced choice, intended to indicate the respondent's preference for a (utilitarian or economic) or (scientific or intllectual) or (aesthetic or artistic) or (any other) relationship.

Sample Frame For: The Student's Own Relationship to the Seashore

I am to the seashore as a . . . . .

driver is to a car	mechanic is to a car	passenger is to a car
story teller is to a story	listener is to a story	animal is to a story
manager is to a hockey team	hockey puck is to a hockey team	uniform is to a hockey team
leaves are to a tree	roots are to a tree	bark is to a tree
lock is to a necklace	bead is to a necklace	string is to a necklace
fruit is to a blackberry bush	thorn is to a blackberry bush	flower is to a blackberry bush
owner is to a fishing boat	captain is to a fishing boat	deckhand is to a fishing boat
window is to a house	door is to a house	roof is to a house
cloth is to a curtain	lace is to a curtain	stitches are to a curtain

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APPENDIX I

Studies of Student Beliefs About Selected Science Concepts

Carried Out at the University of British Columbia

Title: Children's Conceptions of Heat and Temperature.

Source: Science Education, 1979, 63 (2):221-230.

Method of Analysis: 'Children's Idea'

- defined as the child's attempt to explain or in some way account for a problem situation identified by either the child or the interviewer.
- this study represented an initial attempt to describe the framework an individual child was using to interpret aspects of five different tasks involving heat and temperature phenomena.

Sample: 10 twelve-year-old children.

Method of Data Collection: A single, open-ended interview lasting from 40 to 60 minutes where both child and interviewer were free to pose questions and manipulate the materials available.

Indicators of Stability: Ideas were constructed on the basis of common elements of the child's responses over two or more tasks.

- no measure of stability over time nor over different ages were obtained.

Summary of Findings: The analytical construct of children's ideas seemed to be both feasible and fruitful. It allowed the investigator to obtain a fairly detailed analysis of one child's thinking about the tasks used to illustrate some types of heat and temperature phenomena.

Appendix I (continued)

Summary of Findings (continued)

- While all of the subjects possessed a working notion of temperature and could use a thermometer, none of them conceived of it as a property of matter. Rather, it was a quality of hotness or coldness possessed by an object at a given point in time. Only one subject spontaneously discussed matter in terms of particles and he attributed the observations made in the macroscopic world (e.g. expansion of liquid when it is heated) to similar mechanism in the microscopic world (i.e., the particles expand or contract).
- Most of the subjects thought of heat as substance-like and often used terms such as fumes or rays in an endeavour to describe it. These rays had the capability of travelling through all types of matter, although a number of the subjects preferred to use air as a causal mechanism for transferring heat between objects and through objects (i.e., heat travels through the air spaces in objects).
- Some subjects used a two substance model -- heat and cold -- but heat was usually considered the more powerful of the two.
- Generally speaking their explorations of phenomena tended to focus on a single variable (where possible one that was physically related to the phenomena under scrutiny). For example, many subjects argued that soft objects, like wax, melt more easily than hard objects; or a large ice cube takes longer to melt than a smaller one because it has a colder temperature.

Title: Children's Viewpoints of Heat: A Second Look

Source: Science Education, 1980, 64 (3), 323-336.

Type: Group Questionnaire study to cross-validate and extend interview study.

Method of Analysis: Questionnaire items constructed to represent three viewpoints: a kinetic, a caloric and a children's viewpoint. Data was analyzed to determine consistency of response to teach of these viewpoints. Also aggregate profiles were constructed by factor analyzing over subjects.

Sample: 276 subjects in grades 5, 7 and 8.

Appendix I (continued)

Method of Data Collection: Four classroom demonstrations (using phenomena similar to that reported in the earlier study) were performed; after each demonstration the entire class responded to a set of questions. Each question consisted of an explanation utilizing one of three viewpoints and the subjects responded to six bipolar, adjectival scales.

Indicators of Stability: Response consistency to different items from the same viewpoint (stability across items); response patterns over different age groups (stability over age using cross-sectional design).

Summary of Findings: Of the twenty questions used, seventeen clearly broke down into three distinct dimensions corresponding to the viewpoints which were 'built-in' to the questionnaire. This suggests a fairly high degree of response consistency across all of the items representing a given veiwpoint.

- In examining the preferred viewpoint choices of these subjects only one model profile illustrated some preference for a kinetic viewpoint, whereas all three model profiles had a strong preference for the caloric explanations. The children's viewpoint had a generally positive rating on two out of three model profiles.
- There was some indication that an age-related trend might be in evidence as a greater percentage of grade nine students subscribed to the model profile with the positive rating for the kinetic viewpoint.
- It was suggested that this instrument could possible be used as a type of diagnostic assessment to determine both specific beliefs and preferred viewpoints for interpreting heat and temperature phenomena

Title: Student Beliefs About Force in Static Equilibrium.

Source: Master Thesis by J. Aguirre at U.B.C. in 1978.

Type: Natural history.

Method of Analysis: Conceptual Profile for entire sample.

- this consisted of a set of belief patterns constructed by the analyst for each of the five major concept areas considered in the study.
- the belief pattern was a composite statement which represented common response to question/predictions about a given concept.

Sample: 32 subjects ranging from 6 to 14 years of age.

Method of Data Collection: A single interview using three different tasks which involved predictions and explanations of the behaviour of objects which obtain static equilibrium. The tasks, taken from Piaget's vol. XXX Etudes d'Epistemologie Genetique, involved making judgements about the movement of an object resulting from suspended weights attached by means of a string over a single pulley.

Indicators of Stability: Only measure of stability is that of cross-age categorization of belief patters (stability over time).

Summary of Findings: All students interviewed possessed some beliefs about force which allowed them to generate predictions and explanations about the phenomena presented in the three tasks.

- Some beliefs were held by students in all age groups (e.g., a force is acting on an object only if the object is moving); whereas other beliefs seem to be more age specific (e.g., subjects under the age of 11 did not have an intuitive notion of action-reaction in contrast to the older subjects).
- More than half the subjects realized that the net resultant force of two equal forces forming an angle greater than zero degrees do not add up arithmetically -- that is, they have an intuitive notion of vector addtiion.
- No subjects spontaneously used the word force in any of the observations/explanations they made; they tended to use words like pull, tug or pressure.

Title: Children's Beliefs about Free-Fall Motion

Source: Master Thesis by K. Kuhn, U.B.C., 1979.

Type: Natural history documentation.

Method of Analysis: Classification of subject responses into response categories for three tasks.

- Data analyzed at group level.

Sample: 24 subjects in grades 6, 8, 10 and 11. (The grade 11 students had just completed an instructional unit on kinematics.)

Method of Data Collection: A single structured interview using three task settings which involved the free-fall motion of one or two objects.

Indicators of Stability: Cross-age categorization of responses (stability over time).

- possible effects of instruction (using cross-sectional design rather than pre-post design).

Summary of Findings: Many of the younger students tended to view free-fall motion in terms of constant velocity while older students were aware of accelerated motion -- although most thought velocity increased as a function of distance (or displacement) rather than time.

- Most students, even those grade 11 students who had completed a kinematics unit, thought that the weight of an object influenced its free-fall motion (in a setting using two objects with different weights but similar shape, size and surface area).
- The variables addressed in the interview (weight, initial velocity, height from ground) were not treated as acting continuously; often they were thought to act in short impulses or with a dissipating effect.
- Some of the beliefs about motion, which are apparent in the grade 6 students, persisted in the grade 11 students even after formal instruction in kinematics.

Title: Children's Beliefs About Inherited Characteristics

Source: Journal of Biological Education, 1980, 14, 137-146 (with D. Kargbo and E. Hobbs).

Type: Natural history.

Method of Analysis: Tabulation of responses to question according to age.

- classification of explanations into categories.

Sample: 32 subjects aged 7 to 13.

Method of Data Collection: A single structured interview consisting of the presentation of various pictures and accompanying stories about plants, animals and humans. A series of fixed questions followed each story.

Indicators of Stability: cross-age categorization of responses (stability over time using a cross-sectional design).

Summary of Findings: While many students thought that environmentally-induced characteristics could be transmitted to the next generation, this judgement depended in part upon: the type of organism suffering the injury, the lapse of time between sustaining the injury and the bearing of offspring, and the relative influence of both parents.

- On questions of actual inherited traits (e.g. colour of dogs, height in humans) most subjects felt that the mother contributed more to the genetic make-up of the offspring, particularly if the offspring was female. They recognized that some contributions come from the male.

there was some evidence that the older subjects were aware of the possible influence of ancestors in determining the colour of puppies, however, this understanding was very limited and tended to be based on experience rather than on understanding of any genetic principles.

- The reasons given by the subjects to explain their predictions were classified into four categories -- environmental, somatic, naturalistic and genetic. Only the older subjects referred to any explanation which could be construed as having some notion of genetic inheritance.

Title: Children's Beliefs About the Circulatory System

Source: Master Thesis completed by Robin Catherall at the University of British Columbia, 1981

Type: Natural history.

Method of Analysis: Conceptual inventory aggregated over all subjects for three major questions.

- Inventory consists of a set of belief patterns for each of three major research questions: the function of the heart, the methods of blood circulation and the functions of blood.

Sample: 32 students, eight from each of grades 2, 4, 6, and 8.

Method of Data Collection: A single, structured interview using visual aids and some simple activities accompanied by a fixed schedule of questions.

Indicators of Stability: Cross-age categorization of beliefs (stability over time with a cross-sectional design).

Summary of Findings: Most students at all ages were aware that the heart pumped or pushed blood throughout the body. Some students also thought that the heart pushed air through the body either by means of separate passages (mainly younger students) or by mixing the air with the blood in the heart before it is pushed to other part of the body.

- They explained a pulse (which they felt and listened to with a stethoscope) in terms of blood flowing through passages (mainly older students), breathing, brain activity or the direct movement of the heart (mainly younger students).
- Blood was thought to either flow in a continuous fashion from the heart to all other parts of the body before returning to the hear for recirculation (older students) or it flows to one part of the body. Some of the students with the latter belief were not sure whether this blood returned to the heart and some thought it returned in the same vessel in a back and forth fashion.

- Some of the older children were aware that the blood contained both air and food but few were able to postulate reasonable mechanisms for these functions.
- Most students of all ages think that blood is made in the heart, a few think it is made in the stomach and only one said bone marrow.
- There were a number of parallel beliefs between those expressed by the students and those postulated by earlier scientists/philosophers in the Greco-Roman era.

Title: Students' Conceptions About the Vector Characteristics of Three Physics Concepts.

Source: To appear in Journal of Research in Science Teaching (with J. Aguirre).

Type: Interview and questionnaire study based upon rational task analysis of the concept of vector quantity.

Method of Analysis: Inferred rule.

- This was defined as a consistent conception that a subject appears to be using on a given occasion to deal with a particular aspect of an interview situation. If a subject uses the same conception to answer more than half of the questions regarding a particular vector characteristic in the task, then an inferred rule is attributed to that subject for that vector characteristic.

Sample: Twenty grade ten students (age 15 to 17) were interviewed. One hundred and sixty-three grade ten students were given a group questionnaire

Method of Data Collection: A single, structured interview was used and two different task contexts were explained through the use of 8mm film loops and cardboard models. A fixed set of questions was used with each task. The Group presentation used the same tasks, the only difference being that the students selected one of several alternative written responses (based upon typical responses from the interview data) and indicated their reasons in writing rather than verbally.

Indicators of Stability: Response consistency across questions required to attribute rule-useage.

- List of inferred rules will permit future detailed stability check for rule-useage across different task contexts and age-groups.

Summary of Findings: Analysis of the three vector concepts used in the study, presented in terms of separate structural networks, identified ten implicit vector characteristics which provided the basis for the interview questions and the categories of inferred rules.

Appendix I (continued)

- The inferred rules used by the subjects were arranged along a continuum using a physicist's perspective as the criterion for ordering.
- Substantive results indicated that many subjects possessed many intuitions which acknowledged the importance of direction as well as magnitude in making judgements about some physical phenomena. The results also indicated that some everyday experiences (e.g., giving directions to strangers) may lead to some difficulties when analyzing more formal, physics-type problems where a common reference point/framework is assumed. Other sources of potential difficulty associated with the inferred rules used by many students were also illustrated and discussed.

APPENDIX II

Lesson Discourse from Classroom Which Illustrates Persistence of Student Beliefs

(Transcript was provided by S. Haggerty)

Excerpt from lesson, December 1

Post-Lab of Investigation 1-42: The Heat Energy and Temperature of Different Objects

This excerpt illustrates the persistance of students alternative frameworks, in spite of the teacher's repeated attempts to correct their beliefs. The teacher has asked the class to identify the three "factors which determine the amount of heat in an object." The first factor, mass, has been identified. Several students are convinced that density is also one of the factors. The teacher tells them that density is not a factor, but some students are unwilling to give up their belief, no matter what the teacher says.

T: So, mass was one factor, the number of kilograms in an object. What was another factor?

FS: Density

T: Was density the next one?

SS: (...)

T: Not, not directly. On the board for example, which one holds more heat easily, aluminum or lead?

FS: Aluminum

SS: Aluminum

T: (MS1), please stop talking.

MS: (MS1), shut up.

T: So density isn't directly related. The amount of material is of course (...)

SS: (...)

T: Mass is one. What was another?

MS2: Temperature.

T: All right, if you have the same object at a higher temperature, there's more heat than the same object at a lower temperature. So temperature was the second one (writes on board) and the third and final one? -- third factor -- (FS1)?

FS1: The type of material used.

T: O. k. There was aluminum, water, lead. Three factors--temperature, the mass, the type of material.

MS3: Wouldn't material be more, like wouldn't it be more correct to say density than type of material?

T: No, it's not the only factor. Density doesn't really describe the only difference between materials, although it is one of the differences between aluminum and lead. It isn't really directly related to the description of the material. As a matter of fact

MS3: (interrupting) Yeah, but I thought you said this had to do with heat energy.

T: Yes.

MS3: Wouldn't that be (...) involved in heat energy?

T: Density is not really the distinguishing factor. Think of the example of, you're asking a very good question, which is. (pause) Compare that to the readings on page 130. That is, the table giving the effect of the material on the amount of heat in an object (T is referring to a table of specific heats). Now there's a name for the effect of the type of material. It's called the specific heat. Look at the table on page 130. Which one of those is most dense?

S: Lead.

T: Lead has a (...) of 130. It doesn't hold very much heat. Which is one of the low densities?

FS: Methyl alcohol, oh, water.

T: Well, uh, there is one that has a low density and it has a higher reading. Alcohol floats on water, so it has a lower density than water, but it has a higher heat energy. So the density doesn't seem to be directly related. Now you might think it does, but it doesn't seem to correspond to the specific heat. (pause) The type of material is involved. Your question is good and we can see that the type of material is involved, but we haven't really explained why that material should make a difference.

MS1: So, the denser that an object is, the less energy it takes to heat it up.

T: We can't really say that, because it isn't really consistent with the readings that are on that table. What seems to be the factor is what it's made of, and the factor that it's more or less dense doesn't seem to be directly related. At least it's not as simple as that. The mass, temperature and the type of material. Well, if we measure the amount of, now this is something new, get this down in your book. If we measure the amount of heat added to an object, including all of these three together (writes on board: "heat added to an object (J)= mass (kg) X T") heat added to an object. What unit would you measure that in? (By this time, the matter of density as one of the factors has been dismissed. It was not mentioned again that day. However, on the unit test some students still identified density as one of the "three factors which determine the amount of heat present in an object.")

Key: T	teacher
S	unidentified student
SS	several students speaking at once
FS	unidentified female student
MS	unidentified male student
FS1	one particular female student
MS1, MS2, MS3	three particular male students
(nnnnnnnnn)	comments made by observer

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MISCONCEPTIONS, METAPHORS AND CONCEPTUAL CHANGE: ONCE MORE WITH FEELING

D. Bob Gowin

Why do misconceptions persist? One reason is they *feel* comfortable, and we can act with them without the mistake costing us very much. To rid ourselves and our students of misconceptions requires us not only to think differently (change our concepts) but to feel, and then, to act differently. But this view is only to say that getting rid of misconceptions is an act of educating that integrates thinking, feeling and acting.[1]

Any time we face a problem in education the first thing we should do is consult *theory* in order to guide thinking. But most theories are not commprehensive views of our phenomena of interest. Neither Behaviorism nor Classicism are adequate theories of educating. Each is inadequate in its own unique way. Conceptual change views derive from a history of science view and not, say, history of education; that is, conceptual change theory is not about the phenomena of educating. In my view, education is something in its own right that should be studied, a theory developed from clear cases of educative events. An educated person *integrates* thinking, and feeling, and acting. The role *feelings* play has not been a part of conceptual change research, so far as I can see. My focus today on metaphors is beamed at the power metaphors have in combining feeling and thinking. Before I get into that, a few other comments about educating.

Educating, and miseducating, are universal phenomena; schooling and school systems are not. We can have a culture without schooling but not without educating. We can contemplate life without schools but not without that form of educating which helps us lead the good life. Educating is a moral and social enterprise. It is not scientific. It is not a series of cause-and-effect occasions. It is not merely an art. Whether educating is a science or an art is misleading; it is neither. It is social, ethical and political. There are regularities in educative events, but they are artifactual, cultural. They are at base freely chosen human constructions, not deterministic connections of nature revealing uniform laws. Researchers studying educating will misconceive the phenomena if they bring across assumptions, conceptions and principles of science to direct educational research. We will need, not a philosophy of science, but a philosophy of education to guide our work (cf. my essay, "Philosophy of Science in Education," *Fifth Encyclopedia of Educational Research*, Macmillan, 1982, p. 1413-16).

One more general comment. When we use *Educating* as the theory to guide our research, we always try to identify the four commonplaces--teaching, curriculum, learning and governance (social milieu)--in educational events. Further, we follow an orienting view that educating changes the *meaning* of experience and that it empowers individuals to integrate thinking, feeling and acting.

Metaphors

Something seems to happen to us when we first read a fresh metaphor. We reorganize our patterns of previously organized meaning. In that sense disciplined exploitation of metaphor is a form of conceptual grasped meaning. Put differently, if we want to grasp the meaning of new concepts, we should ask the teachers to compose them into metaphors for us. An apt metaphor is probably better than an arid and formally stated hypothesis in trying to find out about something that is unknown. It seems widely to be the case that the frontiers of scientific inquiry are more readily explained metaphorically than formally. The formal reconstructions, like learning, come after. And so it may be with complex conceptual human learning: get thyself a metaphor to ride the unknown. All the rest is algebra.

Metaphors are conceptual archetypes that subsume other concepts. A well-struck metaphor also makes us feel something and guides actions. The early stages of scientific inquiry are guided more often by generative metaphors than by arid hypotheses. So, too, it may be the early stages of learning can be guided by subsumptive metaphors. Strangely enough, some metaphors that work out their meanings in helpful ways also appear initially as misconceptions. If I claim "A paintbrush is a pump," your first impression is likely to be that I am mistaken. When, however, I analyze the claim as a metaphor, you will begin to change your mind and see the channels between bristles transport paint like a pump. Let us see how this works.

(I am freely quoting a brief story about a generative metaphor, a story told by Donald A. Schon.[2])

Some years ago, a group of product-development researchers was considering how to improve the performance of a new paintbrush made with synthetic bristles. Compared to the old natural-bristle brush, the new one delivered paint to a surface in a discontinuous, "gloppy" way. The researchers had tried a number of different improvements. They had noticed, for example, that natural bristles had split ends, whereas the synthetic bristles did not, and they tried (without significant improvement resulting) to split the ends of the synthetic bristles. They experimented with bristles of different diameters. Nothing seemed to help.

Then someone observed, "You know, a paintbrush is a kind of pump!" He pointed out that when a paintbrush is pressed against a surface, paint is forced through the spaces between bristles onto the surface. The paint is made to flow through the "channels" formed by the bristles when the channels are deformed by the bending of the brush. He noted that painters will sometimes vibrate a brush when applying it to a surface, so as to facilitate the flow of paint. The arm pumps the brush to get the paint out.

The researchers tried out the natural and synthetic bristle brushes, thinking of them as pumps. They noticed that the natural brush formed a gradual curve when it was pressed against a surface whereas the synthetic brush formed a shape more nearly an angle. They speculated that this difference might account for the "gloppy" performance of the bristle brush. How then might they make the bending shape of the synthetic brush into a gentle curve?

This line of thought led them to a variety of inventions. Perhaps fibers could be varied so as to create greater density in that zone. Perhaps fibers could be bonded together in that zone. Some of these inventions were reduced to practice and did, indeed, produce a smoother flow of paint.

In ordinary discourse, we call a paintbrush "paintbrush" and we call a pump, "pump." Paintbrushes and pumps are two quite different things and it is not appropriate to call one thing by the other's name. It is true that we can subsume both paintbrushes and pumps under a more general category; for example, they are both examples of tools. But when we think of the two things as tools, we also recognise that they are designed and used for different purposes, and that they operate according to different mechanisms. Hence, we would describe them differently. We might say, for example, that paintbrushes serve to "spread paint on a surface" whereas pumps serve to "move a quantity of liquid from one place to another." We might say that a pump works by "pushing or sucking liquid through a channel" whereas one makes a paintbrush work by "dipping it in paint and then transferring the paint to a surface by wiping the brush across that surface."

When one of the researchers said, "You know, a paintbrush is a kind of pump!" he was himself thinking of the paintbrush as a pump, seeing it as a pump, and he was inviting the other researchers to do likewise. In the language of description, we might say that he was taking the ordinary description of "pump"--something on the order of "an instrument that moves liquid from one place to another by pushing or sucking it through a channel"--as a putative description of "paintbrush." It is as though he were posing a kind of riddle ("How is a paintbrush a pump?") which, once entertained, led him and the other researchers to notice new features of the brush and of the painting process. The constellation of notions familiarly associated with pumping (what Black (1962b))[3] calls the "associated commonplaces") the researchers project onto the painting situation, transforming their perception of pumping. They notice the spaces between the bristles, for example, rather than just the bristles; and they think of these spaces as channels through which paint can flow. One might say that the spaces which had been background become foreground elements, objects of attention in their own right, as in a pump the contained space called a "channel" is a foreground element with a special name of its own. Rather than perceiving the paint as adhering to the surface of the bristles (later scraped off onto a surface), they now see the paint as flowing through the channels formed by the bristles. They can then pay attention to the different bending angles of the natural and synthetic brushes, noting how these different angles make for different ways of compressing channels and thereby affecting the pumping of liquid through the channels; and they can incorporate this observation into a new explanation of the differences in the brushes' performance. They invent ways to smooth out the bending angle of the synthetic brush in order to make it pump (not wipe) paint more evenly onto the surface.

It would be seriously misleading, then, to say that, in making their generative metaphor, the researchers first "noticed certain similarities between paintbrushes and pumps." For the making of generative metaphor involves a developmental process. In the earlier stages one notices or *feels* that A and B are similar, without being able to say similar with respect to what. Later on, one may come to be able to describe relations of elements present in a restructured perception of both A and B which account for the pre-analytic detection of similarity between A and B. Later still, one may construct a general model for which a redescribed A and a redescribed B can be identified as instances. To read the later model back onto the beginning of the process would be to engage in a kind of misleading historical revisionism. (End of story)

* * * * *

Several important ideas come from this clear case of conceptual change. The first idea is that the language of the metaphor permits both concepts and feelings to come together. Felt significance occurs as meaning and feelings are connected. Secondly, the metaphor form creates a minor mode of anlaysis because of the necessity to probe for various relations between the two parts of the metaphor "paintbrushes" and "pumps." A kind of ping-pong back and forth begins. Thirdly, the metaphor stimulates inquiry; events and objects are examined, tested and changed and, as a result, concepts are changed as they are needed to label precisely the new-found regularities in events. Fourthly, the construction of a "general model" or explanatory scheme comes rather late in the inquiry process. This fact signals the generative capacity of the metaphor.

Exploiting or unpacking the meanings of the metaphor actually govern the actions of the inquiry. This approach is neither hypothesis-driven science nor sense-data, observational empiricism. The approach does fit in with a constructionist view (that knowledge is a human construction).

Metaphor and imagination.

Metaphor requires imagination in both maker and receiver. Saying one thing and meaning another, thinking of A as B, tracing out the implications, expressing what is difficult to express literally--all of these acts require imagination. Normal science and routine evaluation require us to collect facts, sort information, assemble claims carefully (even assiduously), and express them clearly with little apparent need of imaginative statements. Indeed, we are surpised if an author tucks in a metaphor here or there.

Useful imagination (the two words clash, like "speculative instruments") requires us to set assiduity aside. In a strong metaphor we should find ourselves responding immediately, as we do to a novel event. The metaphor must move us with its sudden salience. It must jiggle our customary patterns of expectation. It should evoke wonder, a glance both introspective and prospective. A reverberating metaphor brings about an altered state of conscious rationality. The metaphor is the fresh breeze of inquiry.

Metaphor: Combining thinking and feeling.

Some metaphors have a more powerful and immediate appeal to us than do others. Thought by itself moves nothing, claims Aristotle. Since metaphors are important ways of thinking, those metaphors which move us are those which get at thinking and at our depth of feeling. The language of feeling and the language of thought are combined in a well-struck metaphor ("Society is a sea"). In modern philosophy the distinction between informative language (cognitive) and expressive language (noncognitive) has been well worked. The issues are relevant to educating because buried there are all the conflicts over whether value judgments are grounded in facts and reasons or whether they are merely expressions of approval ("I like X.") and direction ("And you should like it too."). Insofar as value judgments are judgments, they are grounded in facts and reasons. Value claims parallel the status of knowledge claims. Insofar as they are claims of value (as in felt significance), however, they parallel expressions of liking, approving, prizing, which carry feeling with them. If we want value judgments to move others to decision, to action, to conviction, to commitment, then we would do well to select language which combines the rational and the emotive. (A well-wrought slogan works this way.) Warranted commitment, like warranted assertion, combines thinking, feeling and action.

A combination of the rational and the emotive occurs in some metaphors. "By its novelty, a poetic image sets in motion the entire linguistic mechanism" (Gaston Bachelard, *The Poetics of Space*, 1964, p. 19). Philosopher Bachelard gives the following analysis. Readers of poetry feel a line of poetry that flutters, resonates and reverberates within. We feel a poetic power rising naively within us. The image touches depths before it stirs the surface. We are moved before we think. We begin to have the notion that we have created it, that we should have created it, because it expresses us so well. As the expression holds us, so it becomes a part of our being, and we begin to express it. The poetic image comes from language (and is, logos, cognitive) and moves to person. (This is why, perhaps, some people are so loath to have poems analyzed; it is soul surgery.)

Metaphors abound at this conference. One frequently heard is "student frameworks" and "alternative frameworks." This language uses a metaphor fragment "framework." What is behind this view? I suspect a conflict of views. One view would lead us to expect architects, builders, carpenters and plumbers all busily building frameworks of knowledge. I call this view a *constructionist* view. It assumes that knowledge is a human construction. Knowledge, like a building, has parts related to other parts--a floor, walls, ceiling. Thus, to analyze a student or teacher framework would be to undertake an analysis of the structure of knowledge. (I show you how to do this analysis in Chapter 4 of *Educating*.)

The other view is, I suspect, simply a way of talking about meaning, and meaning structures. It is a way of seeing how people make sense of things in their experience. Some call this "naive theories" (Resnick) or "espoused theories" (Chris Argryis). The word "theory" in this context carries, for me, the notion of an explanation. A naive theory is the student's way of explaining things. For example, a child, having experienced the pain of fire, may explain boiling water as the water's crying out in pain as the bubbles get louder. This view of framework is a *meaning-making* view. Both views can work together, but the unexplained use of "framework" does not tell us which view is dominant in our analyses.

Final Comments

Most of you familiar with Vee Diagrams of the structure of knowledge will recognize the conceptual side joins with the methodological side at the point of events and objects in the world. I suppose the conceptual side could just as easily be called the "mis-conceptual" side. It would fit with the theme of this seminar. But that would limit us more than necessary. The Vee diagram, which identifies some 9 or 10 elements related in the structure of knowledge, can be taken as a way to identify levels and locations of misconceptions. Students' misconceptions can be seen to involve mistakes at any of these elements in the structure of knowledge. I think I prefer the word "mistakes" to "misconceptions." There are lots of ways for us to make mistakes. Mistakes are part of the knowledge we human beings construct. Scientific truths are "fallible"--as Peirce believed. Just as in the game of baseball, errors are part of the game, not something ever to be excluded from play. Mistaken notions are also part of science, not an ugly excrescence to be removed like warts. For example, the conflict between an atomistic reductionism and sweeping holism are part of biological science; both views lead to mistakes at the level of world views (or perhaps philosophies). Reductionnism--Empiricism and Holism-Rationalism contain unattended assumptions and presuppositions which get scientist and student alike into trouble. In educating we must understand these troubles: what brings them about, what follows from such views, why they exist (Holism, for example, can be seen as an "upward reductionism," as Joseph Schwab called it, making the same assumption as reductionism about the uniformity of nature.) In the context of educating, these issues are important and can be approached using Vee diagram analysis. Another important source of mistakes derives from taking a philosophy of science view as if it were a philosophy of education view.

Each of the numbered elements in the attached Vee diagram is a place where mistakes are made. Changing mistakes into more sensible claims takes a different action at each of these numbered elements in the structure of knowledge.

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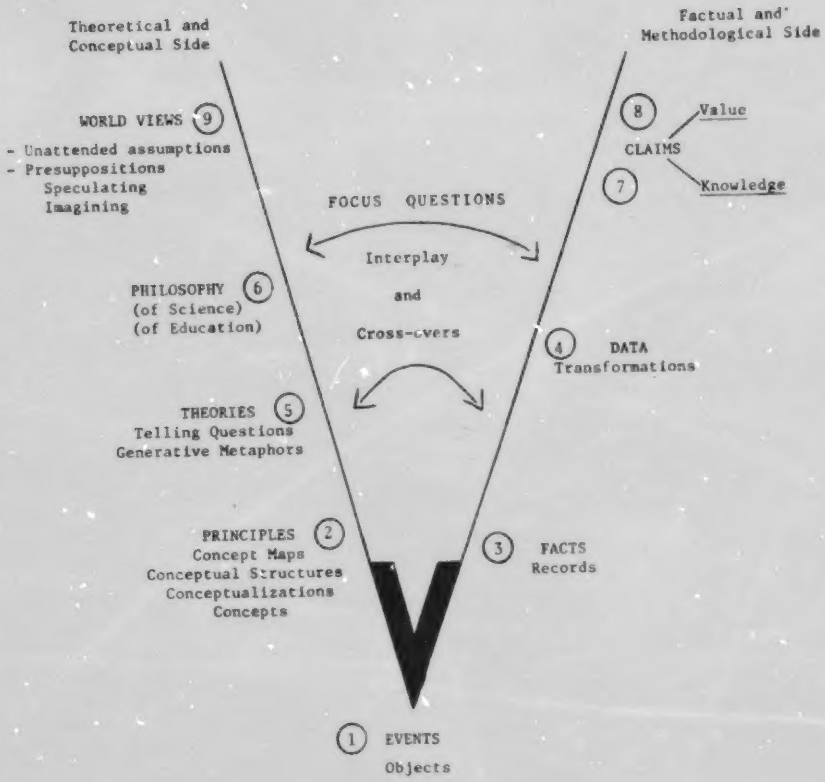
GOWIN'S VEE AND LOCATING MISCONCEPTIONS


Theoretical and
Conceptual Side
Factual and
Methodological Side
WORLD VIEWS 9
- Unattended assumptions
- Presuppositions
Speculating
Imagining
8
7
CLAIMS
Value
Knowledge
FOCUS QUESTIONS
Interplay
and
Cross-overs
PHILOSOPHY 6
(of Science)
(of Education)
4 DATA
Transformations
THEORIES 5
Telling Questions
Generative Metaphors
PRINCIPLES 2
Concept Maps
Conceptual Structures
Conceptualizations
Concepts
3 FACTS
Records
1 EVENTS
Objects

"Concepts without facts are empty; facts without concepts are blind."
I. Kant

"Do Students Understand the Nature and Role of Scientific Concepts?"

Hugh Helm
Cornell University
(On Leave From Rhodes University)

"I can do the problems but I don't understand the theory." Hearing that, you may have wondered whether I had got it the right way around, because pretty certainly you have never actually heard a student say that. Nor, to be truthful, have I; but I have come across many students who have acquired fair facility in solving certain kinds of physics problems, but whose appreciation of the nature and the role of scientific concepts seemed to me to have left much to be desired. This, then, is my concern in this paper, which thus deals with misconceptions or alternative conceptions about the nature of knowledge. As such, it falls within the territory explored in papers presented at this seminar by Margaret Waterman, Donovan, Statkiewicz and Allen, Joseph Novak and Kenneth Strike, among others. Waterman has provided evidence for the existence of alternative conceptions of the tentative nature of scientific knowledge amongst college biology students. In particular, she has found that in her sample there are students who hold to the view that "scientific knowledge is an unchanging accumulation of empirically discovered facts," or, in the words of Novak (1981), "knowledge comes in neat, self-contained, hermetically sealed packets." I believe that similar attitudes towards and views of scientific knowledge can be found amongst students of physics and that this is a matter of importance and concern to those active in this area of science education.

Since I wish to look at the view of concepts implicit in this empiricist attitude, it is appropriate first to set out some aspects of the contrary view which I (and I believe many others) happen to hold. According to the latter, the following are some of the noteworthy characteristics of a concept:

1. Concepts are man-made. To adapt a phrase from Kenneth Strike, "concepts are not worn on the sleeve of nature"; instead, they have to be invented or constructed within the context of some theory, in order to facilitate the description of experience.
2. Some concepts may be capable of definition in terms of other concepts; others are "primitive," that is, they are incapable of definition in this sense.
3. Concepts are not so much right or wrong, as appropriate or inappropriate, useful or useless.
4. The relation defining one concept in terms of others may have logical consequences in certain cases which can no more amount to physical laws than the original definition does.

My experience leads me to assert that the invented or constructed nature of concepts is not apparent to many students; and that the distinction between equations expressing logical consequences of concept definitions on the one hand, and "laws of nature" on the other, is likewise not fully appreciated. The evidence I can present or cite at this stage is partly informal and in some cases indirect. At best, it is suggestive rather than compelling. Even so, I believe it to be worthy of consideration, if only to draw attention to the need for more formal research in this area.

I wish to begin with the second of my assertions. Some years ago, after I had worked through the derivations of the famous equations of rectilinear, uniformly accelerated motion with a class of students of physics-for-the-life-sciences, I decided to probe the extent to which the significance of these equations was apparent to these students. So I asked them the question: "Can one check the validity of these equations by experiment?" and offered the following choice of answers: -

"Yes: - consider the example, $s = ut + \frac{1}{2} at^2$; all the quantities s, u, a and t can be measured, so that it is just a matter of seeing whether the measured quantities satisfy the relationship in question"

OR

"No: - the equations are logical consequences of the definitions of the quantities concerned, and so it is meaningless to speak of them being validated experimentally."

The first time I tried this, there was an overwhelming "yes" vote, and the same finding has been obtained on subsequent occasions with similar groups of students.

It seems to come as something of a shock to students to realize that these equations, which most had previously encountered in high school physics, did not in themselves constitute statements about the physical world, but instead could be used as tools for exploration of that world, i.e., to establish whether or not a given motion was uniformly accelerated. Perhaps it would be fairer to these students to say that they had not previously been encouraged to think about this issue. In that case, the voting exercise might be confirming a suspicion we might have that the matter is, after all, quite subtle.

Even if one accepts this, one might be inclined to say that whether such equations have "law" status or whether they are just logical consequences of definitions is not a matter of real practical importance to the student, whose main concern at this stage is with using the equations in suitable contexts. To this I would object that "understanding" of these equations, meaning among other things, proper appreciation of them as statements of relationships between concepts, implies ability to recognize the contexts in which those relationships are valid; and the realization that the recognition of selection of contexts is an issue must surely depend on some appreciation of the origin of the relationships. But I would go further and argue that failure to come properly to grips with this kind of epistemological issue may inhibit understanding and acceptance of other aspects of physical theory. As an illustration of this which I believe to be far from trivial, consider the problem of finding the relative speed of two particles in a frame of reference in which they are moving in opposite directions with relativistic velocities. For interest's sake, suppose one of the particles to be a photon. Then there is no question that the relative speed in the chosen frame is greater than the speed of light; this is a simple consequence of what is meant by speed and velocity. But it is my experience that when considering this result, many students need reassurance that it does not contradict the assertion, very familiar to them by this time, that "nothing can travel faster than light." What is more, some critics have actually used the fact that this result appears in expositions of the subject as evidence of the allegedly self-contradictory nature of special relativity.

Some teachers and authors of textbooks do tackle the issue of "definition or law?" when introducing the concept of electrical resistance and the mathematical statement of Ohm's Law. (In brief, what does "V = IR" mean - does it define resistance, or does it state Ohm's Law, or is it both?) This example is far too familiar to need elaboration here; I mention it only in order to make the point that if this kind of issue is worth bringing to students' attention in this context, it is worth doing so in others. If nothing else, repeated consideration of the matter might create the impression that it is important, and provoke reflection on it.

Concerning the first of my assertions about students' misconceptions about the nature of concepts, there is nothing in the way of *direct* evidence to report as yet. It is possible to argue that the inability to distinguish laws of nature from logical consequences of definitions is a manifestation of haziness about concept origins, but this conclusion does not follow from this kind of evidence alone. Turning to other kinds of indirect evidence, we may note first of all that it is well known to physics teachers that competent solvers of complex numerical problems may have difficulty in doing what Hewitt (1983) calls "conceptualizing," meaning that they perform much less well in dealing with problems which require little or no calculation but which focus directly on conceptual understanding, or in describing everyday phenomena in terms of physical concepts. (A good deal of evidence concerning this point has been published: see, for example, the references cited by Hewitt.) Rather more direct evidence is currently being gathered in a research project conducted by George Posner and Kenneth Strike. Preliminary results suggest a relationship between the ability to "conceptualize," in Hewitt's sense of the term, and the kind of epistemology held by the student. In a paper presented last year at a convocation of the Northeastern Education Research Association (Strike and Posner, 1982), they suggest that the evidence they had gathered up to that point can be interpreted as follows:

1. "Competence in physics is associated - in some cases, markedly so - with epistemological beliefs."
2. "People who believe the world to be a rational place, who believe objective knowledge is possible, who demand consistency between theory and experience, and who are willing to see through the conceptual eyes of well-confirmed theory do physics better."

As far as the present paper is concerned, what is important about the second of these preliminary findings is that it suggests that competence in physics is *not* associated with narrow empiricism; that the students who "do better," recognize at least to some extent the interplay between theory and experience. This is consistent with, while not yet unambiguous evidence for, the proposition that students who have some feeling for the true character of concepts will do better at "conceptualizing" than those who do not.

If instruction in a subject can be assumed to have *some* influence on a learner's perception of it, then it is worth asking what might be expected of learners in physics in regard to their view of the nature of concepts if this matter is never explicitly brought to their attention and discussed. I think it is fair to claim that epistemological issues are inadequately treated in conventional presentations of physics content (and, one suspects, of the content of other disciplines also). This may be a consequence of the need felt by many teachers to deal as expeditiously as possible with the presentation of the theoretical content, so as to cram as much of the latter into the allotted time as is consistent with the need to provide adequate training in problem solving. It is easy to find examples of textbook presentations of physics which do not explicity discuss the invented or man-made nature of concepts. (The introductory textbook by Arons (1965) is a noteworthy exception.) Elkana (1970) has complained of "new science curriculum programs based on a positivistic instrumentalist philosophy of science, characterized by empiricism, mathematical positivism, elimination of all metaphysics," which foster the view that "science develops by empirical refutation of old theories, objective formulation of 'critical experiments', empirical decisions as to which of the alternatives is the better predicting instrument." I do not believe that teachers or textbook authors who do not sufficiently stress the nature and origin of concepts necessarily subscribe to the view of science to which Elkana objects; but I do think that the effect of their instruction may well be propagate, support or reinforce such a philosophy, whether they approve of it or not. Like Elkana, I regard that as unfortunate. Classroom experience leads me to suggest that, given enough time and room in which to maneouvre, a different approach is possible and has real potential for success. On a number of occasions during the past twenty years, I have been given the chance to share with divinity students some ideas of what physics is and how it works. As part of this enterprise, my approach has been to demonstrate concept evolution and concept choice in a setting familiar to the students, and for this setting I choose

motion in one dimension. When we get around to talking about speed as a measure of "fastness" or "slowness," I try to indicate that while the choice of (distance/time) as our definition of (average) speed is the simplest relationship between distance and time which we can pick on to give us a quantity which is bigger when the object in question goes faster, there is, at this stage, no compelling reason to choose this as our measure. Consideration of what one might take as a measure of "getting faster or slower" emphasizes even more clearly the elements of construction and choice in the formation of the concept. Invariably, someone will come up with the idea that "change of speed in a given time" might be suitable. At this point in the discussion I am careful not to go further in encouragement than agreeing that this could indeed be suitable; and I await other contributions. On every occasion, I have been rewarded with the suggestion that one might also consider "change of speed over a given distance." This is most welcome, because it enables me to begin a discussion on, not which definition of acceleration is "right," but which might be more sensible or convenient to use. I am able to guide this audience in the right direction by pointing out that one kind of "natural motion" - free fall - is characterized by uniformity of acceleration defined as "rate of change of speed" (I keep the vector nature of acceleration out of the picture). I can also point out that in Galileo's day, the issue of how best to define what we would now call acceleration was both real and important, that Galileo gave it prominence in his "Dialogues of Two New Sciences," and that his resolution of the difficulty was an important breakthrough in the development of a science of mechanics.

Students of this type enter readily and indeed enthusiastically into this concept-creating, concept-choosing activity, arousing hopes that if one were to indulge in it with a class of physics students, the response might be equally promising. Unfortunately, with such classes I have seldom felt free to devote what I consider to be adequate time to it. That raises the question of what is really more important: to "cover" a considerable number of topics in a course, or deliberately restrict that number so as to allow more extended treatment of epistemological issues. One way of deciding that question is to consider the degree of association that research studies reveal between appreciation of epistemology and competence in the given subject, and also to see whether there are plausible theoretical links between these two areas. Preliminary findings from such studies as those of Posner and Strike support the view that there should be continuing efforts of this kind, and I think there is a case for research studies looking at particular aspects of the problem, such as connections between the appreciation of the nature of a concept and the performance of certain kinds of physics tasks. In the latter case, one of the difficulties is to find a suitable tool for probing alternative conceptions of a concept (I do not believe it would be profitable to ask a student *directly* "What is your concept of a concept?" or "Where do you think scientific concepts come from?"): suggestions would be welcome! We may find hints as to how best to proceed by searching published accounts of research for results which may be given at least a partial interpretation in terms of an inadequate grasp of the nature of a concept. An examination of what students say or write in descriptions or discussions of physical phenomena may also help towards the design of a suitable instrument.

As an illustration, I shall examine the recent very interesting study by Cohen et al. (1983) of students' concepts of potential difference and current in simple electric circuits. One of their findings is that "students emphasize current rather than potential difference in analyzing electric circuits," and are thus not properly aware of p.d. as the *cause* of the "flow of current." They consider several possible reasons for this: for example, when studying

electric circuits as young children, students will have had "current" emphasized for them which, say Cohen et al., "is a more concrete and intuitive concept than p.d." Other reasons they suggest are the nature of the high school curriculum, which does not always make clear "the relation of cause and effect between p.d. and current" and which may introduce current before potential difference. A point not made by Cohen et al. is that while current is "more intuitive and concrete than p.d.", it nevertheless constitutes a sophisticated abstraction from the phenomena which are studied as illustrations of its presence, and one wonders to what extent the way in which our "official" concept of current is constructed ever becomes clear to the students. I suspect that in many cases it does *not* become clear, that the same is true of potential difference, and that in these circumstances it is not surprising that students show confusion about which can be considered "cause" and which "effect."

Probably many of us have heard students use concept names and the names of their units interchangeably. It is conceivable that this is a manifestation of a *general* vagueness about concepts which in this instance is revealed when students have to use words in discussing phenomena or problems. Other examples could surely be found if sought for.

On the assumption that research studies of the kind proposed will yield results in support of the proposition that some kind of teaching of epistemology is necessary, it is of interest to consider how this might best be done. One possible method of approach, of which I gave an illustration earlier in this paper, is to deal with these matters in context: when a new concept is needed, exhibit as clearly as possible not merely how it is defined (if, indeed, a definition exists), but also why it might be appropriate or useful to define or describe it in that way rather than any other. Novak and various co-workers have sought to apply a more general and systematic strategy of teaching knowledge about knowledge to students from grade seven onwards. They use Gowin's

Vee heuristic (see e.g., Novak and Gowin, forthcoming) which seeks to emphasize not only the key elements in the construction of knowledge in any subject area but also the interplay between them. The construction of knowledge is said to begin with "events or objects observed through the concepts we possess." These events or objects lie at the point of the Vee, the two sides of which represent the "thinking" and "doing" sides of knowledge construction respectively. The "thinking" side includes the relevant concepts, principles, theories and guiding philosophy, and the "doing" includes, in Gowin's terminology, records, transformations of records and knowledge and value claims. Students are given the chance to produce "Vees" for investigations of various kinds, and so they learn among other things to make explicit the concepts, principles and theories which are relevant to the problem. Use of the Vee does not by itself guarantee that the student will acquire a clear view of where concepts come from, but it can certainly form a starting point for consideration of this process.

Finally, we may note that awareness of the man-made or invented nature of scientific and mathematical concepts may alert students to the way in which they arrive at their own concepts. This could be a significant step towards modification of their own view of a concept towards the consensus view.

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A Framework for Conceptual Change With Special Reference to Misconceptions

A. Leon Pines
Leo H.T. West

I. INTRODUCTION

It is indeed appropriate that this conference focus on the research in what might loosely be called "misconceptions".[1] The various research studies on children's pre-conceptions, on the resiliance of these preconceptions, on the alternative conceptions developed during instruction, and on teaching stategies that have potential to change children's conceptions have high potential for influencing the direction of science education in schools. The conference will provide a most valuable contribution to the direction of this research.

Our own interest is broader than this - we are interested in concept learning in general (West, Pines and Sutton, 1983) whether it focuses on "mis" conceptions or "correct" conceptions and we want to place the misconceptions research in that broader context. We don't intend to imply any criticism in that statement. Let us repeat, we believe the focus on misconceptions at this meeting is most appropriate. Our aim in providing the wider perspective is to help focus the findings of the misconceptions research and so to extend its domain of generalizability.

2 TWO SOURCES OF KNOWLEDGE

There is some value in identifying two sources of knowledge in the individual. There is the knowledge that a child acquires from interaction with the environment. We might call this intuitive knowledge, "gut" knowledge, naive knowledge, etc. It is influenced by language, by culture, by other individuals, and so on. It is the child's own sense making of the environment (s)he observes, tempered and manipulated by his/her interaction with parents, peers, television, etc. Its primary characteristic is that it is the child's reality. It is his/her belief system.

The other source of knowledge is formal instruction, discipline knowledge, school knowledge, and so on. It is someone else's interpretation of the world;

someone else's reality. It's primary characteristic is authority. It is "science"; it is what the book says; or what the teacher says. It is approved by a whole bunch of other people who are usually older and more highly regarded than the child.

Our view of mature conceptual learning, drawn from Vygotsky (1962), is the integration of knowledge from these two sources. We find a vine metaphor useful in understanding this. We imagine two vines. represented these different sources of knowledge, the one originating from the child's intuitive knowledge of the world (which we call the upward growing vine to emphasize that it is part in the growth of the child), the other originating from formal instruction (which we call the downward growing vine to emphasize its imposition on the child from above). Mature concept learning involves the intertwining of these two vines. The vine metaphor emphasizes that once the integration occurs, the sources of particular parts of the intertwined vines are impossible to identify - indeed, at that point, the question of source is irrelevant. At the point of integration, however, the sources of knowledge are most important - and it is this aspect that we develop in this paper.

3. INTERACTION OF THE TWO VINES

One can imagine different situations that arise, depending on the nature of our two vines, and these situations have quite different implications for learning and instruction. There are four extremes, which we present diagrammatically in Figure 1 and descriptively in the text that follows.

3a. Conflict situation

Both vines are well established but they are in conflict. In this situation the learner's reality, the ideas that he believes and to which he is committed are in conflict with the scientific principles being presented, which carry with them the authority of science and the endorsement of the school.

Examples of this are the teaching of Newtonian mechanics, when the learner has an Aristotelian-type belief system; or at a more microscopic level, being instructed that work is force times displacement when the learner's intuitive view of work includes situations where no movement is involved (e.g. trying, unsuccessfully, to push a stationary automobile). Mature learning in this case involves transferring one's commitments from one set of ideas to another. It demands the questioning of one's reality; the abandonment of ideas that have been established over a long period - ideas that one knows are still held by members of one's subculture. Merl Wittrock gave a beautiful example of this at the recent AERA meeting at Montreal. He described a visit that he made to a school with Roger Osborne, and his observing Roger present a child with evidence about current flow that was incompatible with the child's articulated model. In response to the demonstration the child replied, "Maybe that's the case here, but if you come home with me you'd see it's different there". This is a graphic illustration of the sort of thing that learners will do in order to retain their own reality and to yet still bow to the authority of science. There is school knowledge and there is real knowledge, and very often students will avoid rationalizing them; they will prevent-to use our vine metaphor - the vines from intertwining. This reduces the conflict for them but leaves them with compartmentalized knowledge. They learn the school knowledge as a set of symbolic knowledge, separate from their reality. Often these students know whether to answer a question from one or other of their compartmentalized knowledges - in school they use the school knowledge, with their peers they use their real knowledge - and so we, as teachers, remain unaware of the true situation, until researchers begin to ask different types of questions, or to interview students in depth. An amusing example of a student trying to decide which of his knowledge worlds to use in answering a question originates in research by Gunstone and White with freshman physics students. They were using Champagne et al's D.O.E. technique and had built a bicycle wheel as a large scale pulley for a large group demonstration. After asking the students to make their prediction, one student asked "Is that a frictionless wheel?" On being told that it was just an ordinary bicycle wheel or an ordinary bicycle axle, the student persisted "Are we to take it to be a frictionless wheel?" Was this student uncertain of which of his knowledge worlds to use? This was, after all, a bicycle wheel, so perhaps he should answer from his experiental knowledge of bicycles and wheels. On the other hand, this was a physics class, so perhaps he should answer using his physics knowledge. In asking his questions, he was demonstrating that he saw that there were different predictions he could make. We would contend that this student had quite separate compartmentalized knowledges and that this accounts for his dilemma.

3b. **Congruent situation**

Both vines are well established but not in conflict. In this situation the student's reality can be integrated with the scientific knowledge without any problems. This is no reality shock, no need to abandon old commitments. There is simply an extension, an integration of one's reality into a bigger perspective. An example is learning about flowering plants. Everyone knows something about flowers, knows that bees are attracted to them, that plants grow from seeds, etc. When the formal science is presented, it merely reinforces these ideas, integrates them into a larger whole, extends one's understanding of the world, and so on.

3c. Symbolic knowledge situation

This is the situation where there is hardly any upward intuitive knowledge vine to interact with the downward scientific knowledge vine. An example of this is the learning of much of freshman organic chemistry. There is little in

the learner's intuitive knowledge that is relevant to the learning of, for example, the substitution reactions of benzene and its derivatives. For the student, this is pure symbolic knowledge. Even laboratory classes do not provide many elements of reality - few freshmen carry out Grignard reactions, catalysed brominations or even nitrations of aromatic compounds. It is even doubtful that many freshmen chemistry students have seen, felt or smelt benzene. So, usually the reactants, as well as the starting materials and products are not part of the learner's experience.

3d. Uninstructed situation

This is the case where there is little or no formal science vine; where all of the learner's knowledge is based on intuitive learning. This is a fascinating area for study, but one that we will not pursue here.

4. APPLICATION OF THIS TYPOLOGY TO MISCONCEPTIONS

An obvious corollary of this typology is that observed misconceptions may be the result of different situations and may require quite different instructional reactions. We take three examples of observed misconceptions to illustrate.

Anderson and Smith (1983) demonstrated the existence of misconceptions about light and colour. They showed, for example, that many students think that light is not composed of a mixture of colours and that "light helps our eyes to see the blue colour [of a blue book]". Roth, Anderson and Smith (1983) showed the existence of certain misconceptions about plant foods, for example that they are things that plants take in. In both of these studies, pre-and post-tests allow the estimation of the extent of such misconceptions in populations of students and the persistence of them over time and instruction.

Using a quite different approach, Fensham (1983) identified the existence of a misconception in a single student after he had completed a freshman course in chemistry. The misconception is best captured by Fensham's transcript.

> "Just after describing for me how liquid acetone evaporated if it is placed on your skin, a first year university chemistry student with good test results was unable to give me any examples of a liquefied gas. When pressed he muttered "Solids, liquids, gases" (a strangely immutable sequence that has neither evolutionary nor biblical support). Eventually, he said he thought the CO_2 in a cylinder was probably liquid. Gases could be liquefied by lowering the temperature, he said. On being asked to describe what would happen if he steadily cooled down the air in a space, he began by quoting, "Air molecules, tiny particles moving very rapidly with energy proportional to temperature." As he cooled them down in thought he held out his hands and slowed down the vibration of his fingers about a point in space. Finally, his fingers stopped and he said, "It's nothing." "What do you mean, has it disappeared"? I asked. "No," he replied, "but it's no longer a gas, and it's not a liquid or a solid. They are all just there suspended in space. It's nothing"!"
>
> (Fensham, 1983, 3)

We classify these misconceptions as three different types, deriving from three different learning situations - respectively a conflict situation, a congruent situation and a symbolic knowledge situation.

4a. Misconception deriving from a conflict learning situation

The scientific view that white light is composed of a range of "colours" and that a book appears blue because only blue light is reflected is counter-intuitive. "Blueness" is a property of a blue book. Our whole language implies that. It is hard to imagine anything that is more real to a child than colour. To adopt the scientific explanation requires one to reject that reality. In order to achieve such a revolutionary change in understanding requires some special instructional procedures that are not common in science teaching. The types of strategies recommended by Champagne et al (1981), Erickson (1980), Nusbaum and Novick (1981) and Posner et al (1982) seem appropriate here. These strategies usually involve three phases - the first an awareness phase, the second, a disequilibrium phase, the third a reformulating phase. The awareness phase for Erickson involves what he calls "experiential and clarification manoevres" in which the teacher provides a range of experiential activities followed by class discussion to elicit and emphasize the existence and nature of competing view points in the class (Erickson, 1980). Nussbaum and Novick (1981) proposed and tested the effectiveness of a similar technique. Champagne et al, proposed the use of a set of physics problems and student teacher dialogue with the same aim. Posner et al suggested that this phase involves the student actively seeking to make sense of new learning within his existing framework and finding that unsatisfactory. They suggest, here, that teachers should spend a substantial portion of their time diagnosing student thinking errors and identifying defensive moves by students to resist conceptual change.

The disequilibrium phase for Erickson and Posner et al involves the use of anomalies introduced by the teacher which challenge existing frameworks. Nussbaum and Novick called the anomalies they used "discrepant events". They involved the students in articulating the lack of consistency between the events and their particular framework. Posner et al state, and others imply, that during this phase the teacher needs to adopt an adversary role in the sense of a Socratic tutor.

The reformation phase involves, for Champagne et al, Erickson, and Nussbaum and Novick, the presentation of the experts' conceptualization with emphasis on the resolution of anomalies. We should note here that Nussbaum and Novick's investigation of the application of such a set of strategies was less successful than anticipated. Some of the affective components of concept development discussed by Head and Sutton (1981) and included in Posner et al (1982) (see also West and Pines, 1983) may be important in this regard.

4b. Misconceptions derived from a congruent learning situation

Misconceptions to do with the scientific view of plant food and photosyntheses are quite different in nature. The student's intuitive idea of the concept "food" shares a great deal with the concept of "plant food". This is illustrated, with considerable over simplification, using a Venn diagram (Figure 2). The transition from an intuitive meaning for food to the scientists meaning for plant food is relatively smooth. It does not involve abandoning one framework for another, just the extension of the intuitive meaning to a new meaning, and the abandoning of some aspects of the intuitive meaning in favour of new aspects. Such evolution of word meanings is common in the experience of children.

With regard to instruction, it would make little sense to use the awareness-disequilibrium-reformulation approaches that are proposed above. We do not wish to shake the student's belief in his intuitive meaning of food. Nor does it make any sense to demonstrate situations which are inconsistent with his concept of food. Rather we would be inclined to have the student articulate his own concept of food and use this to develop the scientific concept. Techniques like Novak's concept mapping, Ausubel's comparative organizers, Schaefer's free definition and word association, even the use of Venn Diagrams would all be appropriate techniques for moving the student towards acquiring the scientist's concept of food in plants.

4c. Misconceptions derived from a symbolic knowledge situation

Fensham's example of a misconception is different again. It is a gross misconception in the sense that the student cannot relate the behaviour of molecules to bulk properties and behaviour of matter (the states of matter). Yet it does not really matter. For the student this misconception is irrelevant. It creates no barrier to his understanding of either the bulk properties of matter nor to its molecular properties. The latter is so, because these areas of learnings are self contained areas of symbolic knowledge which bear no relationship to the real world knowledge held by the students.
(Indeed, they bear little relationship to the real world. At the freshman level the chemistry deals with "ideal" gases and liquids, i.e. some mythical models that are simplified generalization of reality). Eventually, for some students, it may be necessary to remove such misconceptions. But at this time this misconception will neither inhibit the student in his subsequent learning, nor will it provide for him any worrying conflicts. As his symbolic knowledge becomes more sophisticated, and if he is inclined to do so, the student might resolve the relationship between the chemist's models of systems and their behaviour and the real world. His concept would then be, of course, much more mature.

(As an autobiographical aside, it took one of us years to appreciate the real world significance of $\Delta G = \Delta H - T\Delta S$. I could, of course, use the relationship to predict the direction of change; to couple it with Cp values to make predictions about the behaviour of chemical systems at different temperatures and pressures; to transform data using this equation to determine the values of some molecular quantities like the potential well depth of the pair-wise interaction between molecules; and so on. At the same time, I had tended to regard change in the world as being energy driven, and I am sure that if I had been interviewed I would have asserted that. It is only in recent years that I have appreciated that at low temperatures the ΔH term dominates the ΔG expression, and it is for this reason that changes in our world experience tend to be energy driven (LHTW).

5. CONCLUSIONS AND SOME UNRESOLVED QUESTIONS

Where does this analysis lead? What contribution can it make to this conference? In what ways does it add to the assimilation/accommodation distinction of, among others, Posner and Strike? As a conclusion to this paper, let us tackle the last question first and then lead from there to answers to the other questions.

Our first two learning situations appear to correspond, respectively, to accommodation and assimilation, as these terms are used by Posner and others. Yet their derivation is different - and in that direction lies one of their values. They are derived from an analysis of two types of learning, their nature and their source. This enables us to identify a particular area of content as being of one type or the other. In addition this analysis yielded a third learning situation that is neither accommodation nor assimilation. Further, it seems clear that observed misconceptions can be identified with one of the three learning situations, thus illuminating the cause of the misconception and indicating which instructional techniques will be useful in dealing with the misconception.

It is this latter point that led us to making this contribution to the conference. There are many concepts in science. We can envisage the situation where researchers will "butterfly" around the science curricula, demonstrating the existence in students of this misconception here and that misconception there, and so on. Ultimately that research will be of little value. We need to be able to place some order on such information - and one way to do that is to identify the nature of and the causes of misconceptions. Even if our particular analysis turns out to be unproductive, we believe it indicates what needs to be done. If it is possible to identify a small number of types of misconceptions in science, and to relate these to some theory or theories of learning which explain both their nature and their cause, then research in misconceptions in science will be able to produce some generalizations that will be extremely valuable in science education. We believe that our analysis provides such a framework. If, on closer inspection this proves not to be so, we urge researchers in this area to search for a better framework to achieve similar aims. Without this, the field of research in misconceptions in science will provide only a "band-aid" or "finger-in-the-dyke" strategy for science education.

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Footnote

1. We use the term "misconception" throughout this paper because of its use in the conference title. we should record, however, that we feel uncomfortable with the negative connotation implied about a student's conceptions by the use of the "mis-" prefix.

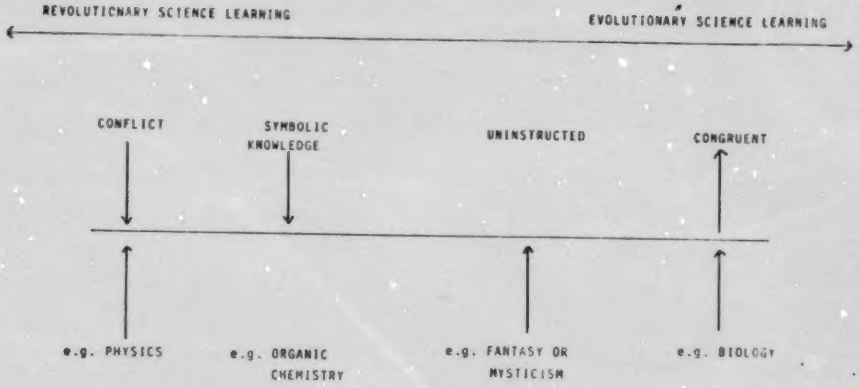

FIGURE 1: FOUR EXAMPLES OF SITUATIONS THAT ARISE USING THE VINE METAPHOR

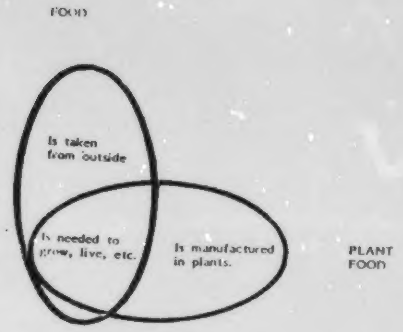

FIGURE 2: A SIMPLIFIED REPRESENTATION OF THE RELATIONSHIP BETWEEN A STUDENT'S INTUITIVE MEANING OF "FOOD" AND THE CURRICULUM MEANING OF "PLANT FOOD" AS A LEAD-IN TO PHOTOSYNTHESIS.

A MODEL OF CONCEPTUAL CHANGE: PRESENT STATUS AND PROSPECT

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In a series of papers, my colleagues and I have described the process of conceptual change (Posner et al, 1979, 1982, Strike and Posner, 1983, P. Hewson, 1980, P. Hewson and M. Hewson, 1981, P. Hewson, 1981, P. Hewson, 1983). It seems appropriate at this time to take stock of our model of conceptual change, to integrate and extend our various accounts used to describe conceptual change into a generic description, to explore the model's potential future application sites, and then to suggest some limitations of our current approaches.

A Model of Conceptual Change

The model of conceptual change as presented in Posner et al (1982) and P. Hewson (1980) described the process of "accommodation" (or "conceptual exchange"), distinguishing this process from "assimilation" (or "conceptual capture"). The difference between these two types of conceptual change centers on the degree to which old and new conceptions are reconcilable and, therefore, the degree to which a new conception can be integrated into an existing conceptual context.

Although "conceptual change" refers to both processes, the focus of our theoretical and empirical work to date has been on accommodation. We have described accommodation as consisting in two dimensions, one describing the four conditions for an accommodation, the other describing the features of a conceptual ecology which influence the specific direction a conceptual change follows.

As previously described, the four conditions for an accommodation are as follows:

(1) **There must be dissatisfaction with existing conceptions.** Scientists and students are unlikely to make major conceptual changes until they believe that less radical changes will not work.

(2) **A new conception must be minimally understood.** The individual must be able to grasp how experience can be structured by a new conception sufficiently to explore the possibilities inherent in it.

(3) **A new conception must appear initially plausible.** Any new conception adopted must at least appear to have the capacity to solve the problems generated by its predecessors, and to fit with other knowledge, and experience. Otherwise it will not appear a plausible choice.

(4) **A new conception should appear fruitful.** It should have the potential to be extended, to open up new areas of inquiry and to have technological and/or explanatory power.

As we have discussed previously (Posner et al, 1982), an individual's current cognitive resources, his or her conceptual ecology, will influence the selection of a new conception. The literature in philosophy of science and our own work have suggested that the following kinds of resources are particularly important determinants of the direction of an accommodtion.

(1) **Anomalies:** The character of the specific failures of a given idea are an important part of the ecology which selects its successor.

(2) **Analogies and metaphors:** These can serve to suggest new ideas and to make them understandable.

(3) **Exemplars and images.** Prototypical examples, thought experiments, imagined or artificially simulted objects and processes all influence a person's intuitive sense of what is reasonable.

(4) **Past experience:** Conceptions which appear to contradict one's past experience are unlikely to be accepted.

(5) **Epistemological commitments:**

(a) **Explanatory ideals:** Most fields have some subject matter-specific views concerning what counts as a successful explanation in the field.

(b) **General views about the character of knowledge:** Some standards for successful knowledge such as elegance, economy, parsimony, and not being ad hoc seem subject matter neutral.

(6) **Metaphysical beliefs and concepts:**

(a) **Metaphysical beliefs about science:** Beliefs concerning the extent of orderliness, symmetry, or nonrandomness of the universe are often important in scientific work and can result in epistemological views which, in turn, can select or reject particular kinds of explanations. Beliefs about the relations between science and commonplace experience are also important here.

(b) **Metaphysical concepts of science:** Particular scientific conceptions often have a metaphysical quality in that they are beliefs about the ultimate nature of the universe and are immune from direct empirical refutation. A belief in absolute space or time is an example.

(7) Other **knowledge:**

(a) **Knowledge in other fields.** New ideas must be compatible with other things people believe to be true.

(b) **Competing conceptions:** One condition for the selection of a new conception is that it should appear to have more promise than its competitors.

These two dimensions of conceptual change relate directly to each other as summarized in Table 1. (Insert Table 1 about here.) Let us examine these relationships more closely and thereby explicate a model of conceptual change.

	CONDITIONS FOR AN ACCOMMODATION			
FEATURES OF A CONCEPTUAL ECOLOGY	Dissatisfaction	Minimal understanding	Plausibility	Fruitfulness
Anomalies	X		X	X
Analogies & Metaphors		X	X	
Exemplars and Images		X	X	
Epistemological Commitments	X		X	
Metaphysical Beliefs and Concepts	X		X	
Past Experience	X		X	X
Other Knowledge	X		X	X

Table 1. The Relationship of Features of a Conceptual Ecology to the Conditions of an Accommodation.

Dissatisfaction with Existing Conceptions

Generally, a new conception is unlikely to displace an old one, unless the old one encounters serious difficulties and a new understandable and initially plausible conception is available that resolves these difficulties. That is, the individual must first view an existing conception with some dissatisfaction before he will seriously consider a new one. Dissatisfaction results from the individual experiencing one or more of the following conditions:

(1) A conception is incapable of interpreting experiences presumed to be interpretable (resulting in an anomaly).

(2) A conception is seen to be no longer necessary in the interpretation of experiences previously considered significant. This may be a consequence of another conception's greater success in interpreting the experiences or another conception reducing the significance of the experiences.

(3) A conception is incapable of solving some problems that it presumably should be able to solve.

(4) A conception violates an epistemological or metaphysical standard.

(5) The implications of a conception are unacceptable.

(6) A conception becomes inconsistent with knowledge in other areas.

Let us focus for a moment on anomalies, which is the concern of several papers presented at this seminar. Each time a person unsuccessfully attempts to assimilate an experience or a new conception into his existing network of conceptions, that person experiences an anomaly. An anomaly exists when one is unable to assimilate something that is presumed assimilable—one simply cannot make sense of something.

I am not as optimistic about the instructional value of anomalies as many participants of this seminar. Let me explain. When faced with an anomaly, the individual has several alternatives. One may come to the conclusion that one's existing conceptions require some fundamental revisions (i.e., an accommodation) in order to eliminate the conflict. But this is the most difficult and, therefore, the most unlikely approach, especially when there are other possibilities:

(1) rejection of the observational theory;

(2) a lack of concern with experimental findings on the grounds that they are irrelevant to one's current conception;

(3) a compartmentalization of knowledge to prevent the new information from conflicting with existing belief ("Science doesn't have anything to do with the 'real' world"); and

(4) an attempt to assimilate the new information into existing conceptions (e.g., "Newtonizing" relativistic phenomena).

This analysis suggests that the presentation of anomalies will produce dissatisfaction with an existing conception only if:

(1) Students understand why the experimental finding represents an anomaly;

(2) Students believe that it is necessary to reconcile the findings with their existing conceptions;

(3) Students are committed to the reduction of inconsistencies among the beliefs they hold; and

(4) Attempts to assimilate the findings into the students' existing conceptions are seen not to work.

Given the improbability that all these conditions will be met, it is no wonder that few students find their current conceptions weakened by anomalies. Why consider alternatives to a view they hold when they are unconvinced of the indadequacy of their conceptions?

Minimal Understanding of a New Conception

In order for students to consider an alternative conception, they must understand it at least at a minimal level. Understanding an idea requires that it be viewed within a context of other ideas (Strike and Posner, 1983). That is, understanding entails finding a niche within a conceptual ecology. A full understanding of an idea requires the ability to see a wide range of implications of the idea and to apply it to complex and novel situations (Strike and Posner, 1983). Clearly, this level of understanding is not required to begin to entertain the possibility of the reasonableness of a new idea. All that is required for a minimal understanding is having enough sense of the idea to begin to explore its possibilities and to see some of its implications. Two requirements suffice for minimal understanding:

(1) Ability to construct or identify a framework in which to locate the new idea. Metaphors and analogies enable students to borrow frameworks from other contexts. Images enable students to use visual frameworks for this purpose.

(2) Ability to attach the framework to the world in at least prototypical ways. Exemplars are standard cases to which a framework has been applied.

The importance of frameworks in understanding ideas is analogous to the cognitive scientists' concern for "representation of knowledge." As cognitive scientists point out, ideas cannot function psychologically unless the student can internally represent them. Representations in the form of images and/or networks of propositions function both passively and actively. They function passively as a format into which information must be fit. In paragraph comprehension tasks, for example, anomalous sentences are confusing (i.e., not understandable) because they cannot be fit into the representations being built and, thus, are not easily entered into the reader's memory (Bransford & Johnson, 1973). Representations also function actively as a plan for directing one's attention and conducting purposeful searches (Neisser, 1976). The inability of readers to remember an anomalous sentence in an otherwise coherent paragraph may be attributed to the readers' inattention to it.

Initial Plausibility of a New Conception

Regardless of how understandable one finds a conception, it may still appear counterintuitive. What determines whether a conception will be counterintuitive or, on the other hand, plausible?

Initial plausibility can be thought of as the anticipated degree of fit of a new conception into an existing conceptual ecology. There appear to be at least five ways by which a conception can become initially plausible.

(1) One finds it consistent with one's current metaphysical beliefs and epistemological commitments, i.e., one's fundamental assumptions.

(2) One finds the conception to be consistent with other theories or knowledge about which one is aware.

(3) One finds the conception to be consistent with past experience.

(4) One finds or can create images for the conception, which match one's sense of what the world is or could be like.

(5) One finds the new conception capable of solving problems of which one is aware (i.e., resolving anomalies).

(6) One finds the conception to be analogous to some other conception with which one is already familiar.

Fruitfulness of a New Conception

A person becomes committed to a conception because it helps interpret experiences, solve problems and, in certain cases, meets spiritual or emotional needs. A new conception should do more than the prior conception for the person, if it is to be considered fruitful, but it must do so without sacrificing any of the prior conception's benefits, or must provide sufficient incentives for any required sacrifice. It is no wonder, then, that a few anomalous pieces of data cannot shake a person's commitment to a prior conception (e.g., scientific creationism), even though a new conception (e.g., evolution) resolves the anomalies. Assuming a person can believe in a new conception that resolves apparent anomalies while doing as much for the person as the prior conception, then the person may actively attempt to map the new conception onto the world and to extend it. If doing this leads to new insights and discoveries, then the new conception will appear fruitful and the accommodation of it will seem persuasive. A new conception will appear fruitful to the extent that students are aware of, can generate, or can understand novel practical applications or experiments which the new conception suggests.

The Character of Accommodation

My description of the four conditions of a successful accommodation may have suggested a fairly straightforward linear process: students' dissatisfaction with an existing conception; followed by the students' finding a new conception understandable; leading to an initial belief in its plausibility; and concluding with the belief that the new conception is ulitmately fruitful.

However, it should be clear that this account is oversimplified, since many basic conceptions are so complex that at a particular time one is likely to accommodate certain aspects but not others. We have, of course, described accommodation as a radical change in a person's conceptual system. That an accommodation is a radical change does not, however, entail that it is abrupt. Indeed, there are good reasons to suppose that for students accommodation will be a gradual and piecemeal affair. Students are unlikely to have at the outset a clear or well-developed grasp of any given conception and what it entails about the world. For them, accommodation may be a process of taking an initial step toward a new conception by accepting some of its claims and then gradually modifying other ideas, as they more fully realize the meaning and implication of these new commitments. Accommodation, particularly for novices, is best thought of as a gradual adjustment in their conception, each new adjustment laying the groundwork for further adjustments but where the end result is a substantial reorganization or change in their central concepts.

Accommodation can be viewed as a competition between conceptions (P. Hewson and M. Hewson, 1981). Once students are aware of a minimally understandable and initially plausible alternative to an existing conception, the relative status of these conceptions is the issue. Dissatisfaction with the existing conception decreases its status, while exploring the fruitfulness of an alternative conception increases the alternative's status (Hewson, 1983). As long as the existing conception's status is greater than the alternative's (for whatever reason), accommodation will not proceed.

Whenever the alternative's status exceeds the existing conception's status, accommodation, for the time being, will move forward. But, as I have discussed, many factors affect status. Therefore, competition between conceptions results in a process of accommodation characterized by temporary advances, frequent retreats and periods of indecision.

Our research also indicates that what may initially appear as an accommodation may turn out to be something less than that (Posner et al, 1982). Typically, students will attempt various strategies to escape the full implication of a new conception or to reconcile it with existing beliefs. Accommodation may, thus, have to wait until some unfruitful attempts at assimilation are worked through. It rarely seems characterized by either a flash of insight, in which old ideas fall away to be replaced by new visions, or as a steady logical progression from one commitment to another. Rather, it involves much fumbling about and many false starts and mistakes.

Application Sites

Three application sites for the conceptual change model seem worth exploring: student learning, teacher thinking and educational change.

Student Learning

Accommodation is necessary whenever a teacher wants students to meaningfully learn a new (or "goal") conception, which is at odds with a student's prior (or "naive") conceptions. Students develop naive conceptions (or, as Driver (1983) prefers, "alternate frameworks" and Viennot (1979) terms "spontaneous theories") as they "construct understanding,...look for meaning,...and try to find regularity and order in the events of the world, even in the absence of complete information" (Resnick, 1983, p. 472).

A perusal of this conference's program suggests the range of topics in science and mathematics requiring a conceptual change approach.

One might conclude from this conference that if the student does not have a well-developed naive conception, then the conceptual change model does not apply. However, the most important aspect of the conceptual change model is its analysis of the conceptual ecology in which new conceptions must fit. That is, the model stresses and explicates the conceptual context of learning. Therefore, even in the absence of well-developed naive conceptions, new ideas must still fit into some conceptual ecology, if the student is to learn the new ideas meaningfully. This, of course, is true by definition of the term "meaningfully."

If conceptual ecologies play a significant role in all conceptual change, then we will need to know a great deal about their features and the way they affect learning new conceptions. The research that I am engaged in here at Cornell with Ken Strike and others (Strike and Posner, 1982) is designed to begin to map out college students' epistemological and metaphysical assumptions and to determine the relation of these fundamental assumptions to accommodative learning of physical conceptions. Our preliminary results (Strike and Posner, 1982) suggest a rather strong association between certain fundamental assumptions and competence in solving certain physics problems. These problems require students to withhold their intuitive beliefs while they analyze the problem. Like other researchers, we have found an appalling lack of ability to solve even elementary problems of this type in students completing as many as three years of college physics courses. We are now trying to determine which fundamental assumptions are most strongly associated with success in solving various sorts of problems when we control for physics background.

Teacher Thinking

Students are not the only potential targets of conceptual change strategies. Ed Smith at this seminar suggested that teachers also must change their conceptions if students are to change theirs. Two sorts of teacher conceptions are relevant. First, the teachers' own scientific theories must be in accord with those they are teaching, if we expect teachers to mediate student learning. Since many teachers (particularly at the lower educational levels) lack the extensive science background necessary for accommodation, they are likely to hold many of the same naive conceptions their students do.

Second, Smith (see also Smith and Anderson, 1983) points out that teachers' conceptions of teaching require fundamental change if they are to produce accommodation in their students. Smith reports that elementary school teachers using the SCIIS program conceived of teaching science in one of two ways, labeled "didactic" and "discovery." Didactic science teaching entails use of convergent questions leading to the development of a story line with experimental results employed in support of the story line. Didactic teachers rejected with little or no explanation "incorrect" student responses, giving hints and explanations to help guide discussions. The didactic view of teaching supports a knowledge acquisition view of learning.

In contrast, discovery teaching supports a view of learning in which "students develop knowledge for themselves through active investigation and discovery" (Smith and Anderson, 1983, p. 19). The focus of the teacher is on students' observations and measurement, acceptance of student responses to questions, and an absence of teacher presentations.

Neither view of teaching produced conceptual change in students. Didactic teaching ignored or rejected students' naive conceptions with the result that few students learned the content in a meaningful way. Discovery teaching allowed for the further development of naive conceptions but begged the question of the discrepancy between goal and naive conceptions. The discovery view assumes that an observation speaks for itself. That is, goal conceptions inductively derive from empirical observations. Smith and Anderson found no evidence to support this view.

In order to use SCIIS to bring about conceptual change in students, teachers needed to change their conceptions to a conceptual change view of teaching. Such a view requires the teacher:

> to bring out the students' preconceptions, provide a base of relevant experience and observations, challenge the students' misconceptions with appropriate questions and evidence, clearly present the scientific alternative conception, and help the student to realize the greater power and usefulness of the new conception.
>
> (Smith and Anderson, 1983, p. 19)

Ironically, the SCIIS program explicitly supports this view and provides a teacher's guide to help the teacher effect conceptual change. However, teachers interpreted and utilized the teachers' guide in a way that was consistent with their own view of teaching. Therefore, if teaching is to change, teachers' conceptions of teaching must change. Whether this conceptual change problem is best approached through teachers' guides, inservice or preservice workshops, or some other means, and how well our current model of conceptual change will function as a blueprint for such work remain important but currently unresolved questions.

Educational Change

If our conceptual change model has anything to say about education in general, it is that teaching and learning occur within a context of ideas. Therefore, if we want to extend our application of the model beyond learning and teaching to science education in general, we might attempt to explain educational change as a function of cultural context (Posner, 1983). This approach interprets the degree of success of a new idea or practice in terms of the availability of a niche within the network of prevailing views about science, scientists, and education (Posner, 1983). Without an available niche, science educators and the public alike will consider a change unreasonable.

Previously, I have sketched the current context of science education in terms of the epistemological, psychological and socio-political legacies left to us by our predecessors (Posner, 1983). Therefore, rather than describing these ideas again here, I wish only to suggest a research agenda. Just as my colleagues and I have been able to make some theoretical progress by attempting to explain unsuccessful attempts of conceptual change in students (Posner *et al*, 1982), and Smith has made some progress by describing what can go wrong in teaching, I would encourage researchers to study unsuccessful attempts at educational change. Such research would identify sources of difficulty in attempts to implement new curricula (such as Project Physics), evaluation methods (such as criterion-referenced evaluation), or teaching methods (such as "inquiry" methods), technologies which differ in significant ways from common practice. The aim would be to develop a theory of educational change by describing the epistemological, psychological and socio-political barriers to such changes.

A Look Forward

Up to the present time, conceptual change theory like most all learning theories has been applied to individual student learning. This work seems to be based on the assumption that learning (whether of the rote, assimulative or accommodative kind) is determined by what the teacher says or does, what the textbook says, and what the students previously have experienced or currently believe, know or can remember. This view is obviously only partially true. Sociologists might even claim that it is true but trivial. Clearly students experience instruction in a social context. The classroom is a social system with rules of procedure, a mix of individuals with different social as well as cognitive backgrounds, and established communication and authority patterns. Schooling is more than a place of learning. Schooling is also one of our society's most powerful institutions, and students and teachers behave according to their institutional roles. As institutions, schools serve not only an educational function, but also social control and sorting functions. All these sociological aspects of schools and classrooms affect teaching, learning, evaluation and curriculum. As Schwab (1977) has pointed out, it is a mistake to assume student learning can be studied and curricula developed from a purely psychological or epistemological perspective, much less from the perspective of a particular psychological or epistemological theory.

This broadening of perspectives on student learning should not be unexpected from a conceptual change point of view. All that I am suggesting is that we broaden our view of conceptual ecologies at least to include sociological beliefs and ideas. Herb Lin is presenting a paper at this confernece describing the work he has begun studying physics classrooms from an anthropological perspective. M. Hewson and Hamlyn (1983) reported at AERA this year on a cross-cultural study of children's concepts of heat. In so doing, they showed the cultural dependence of conceptual ecologies. Clearly this is only the beginning of a broadening of research on conceptual change that will eventually lead to more powerful theories and ultimately to improved education.

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Teaching For Conceptual Change: Some Ways of Going Wrong

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As the present seminar and the volume of papers attest, it is now well established that students generally possess conceptions relevant to curricular topics before they begin study of them. It is further clear that such preconceptions often persist despite instruction on scientific theories which contradict them. The discrepancies between the students' post instruction conceptions and the scientific theories as taught often represent important failures of instruction.

Viennot (1979) among others has argued that students' preconceptions persist in part because they have worked so well in the everyday world of students. That similar ideas have sometimes held sway among scientists for centuries is testimony to their explanatory power. Anderson and Smith (1983) described how preconceptions are often compatible with much of the student's experience of instruction. Thus, preconceptions are active competitors with scientific alternatives as organizing structures for students experience of instruction as well as for their everyday experience.

The existence and persistence of students preconceptions implies that learning involves not simply the acquisition or formation of new concepts. It involves the modification of existing concepts or their replacement with appropriate alternatives, i.e., conceptual change (Toulmin, 1972).

Several researchers have proposed models of conceptual change. Posner, Strike, Hewson and Gertzog (1982) propose four conditions that must be fulfilled if accommodation* is likely to occur, that is, if students are to make changes in their central concepts"

1) There must be dissatisfaction with existing conceptions.
2) A new conception must be intelligible.
3) A new conception must be initially plausible.
4) A new conception should appear fruitful (lead to new insights and discoveries)

Nussbaum and Novick (1982 a,b) describe a general teaching strategy for use where significant accommodation is expected.

1. Initial exposure of students' alternative conceptions through their responses to an "exposing event;"
2. Sharpening student awareness of their own and other students' alternative conceptions, through discussion and debate;
3. Creating conceptual conflict by having the students attempt to explain a discrepant event;
4. Encouraging and guiding cognitive accommodation and the invention of a new conceptual model consistent with the accepted scientific conception.

In one study Nussbaum and Novick (1982b) applied their model to the development and assessment of an instructional strategy designed to promote specific changes in sixth grade students' conceptions of the nature of gases. The authors reported that the strategy was "highly efficient in creating cognitive challenge and motivation for learning," but "did not lead to the desired total conceptual change in all students." In fact only one of the seventeen students was reported to have adopted the intended goal conception. The others ended up with one of five conceptions the investigators identified as intermediate between the students' original preconception and the goal conception. Another five students progressed as far as the last intermediate conception. The remaining students, about two-thirds, completed instruction with several misconceptions. The major conclusion drawn by the authors was "that a major conceptual change does not occur, even with good instruction, through revolution but is by nature an evolutionary process."

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*Both Posner, et al., (1982) and Nussbaum and Novick (1982a,b) use the term accommodation to refer to instances where students central conceptions undergo change in contrast to instances in which new information is incorporated with existing conceptions with little change (assimilation).

The present paper reports results of a study in which we analyzed the changes that did (and did not) occur in the conceptions of a class of fifth-grade students as they experienced instruction designed to change their conceptions of how green plants get their food. The instruction was based on Chapters 3-6 of the Rand McNally SCIIS Communities unit (Knott, Lawson, Karplus, Thier and Montgomery, 1978). This sequence incorporates elements of the conceptual change models summarized above.

The impact of instruction on students in our study was similar to that reported by Nussbaum and Novick (1982b). Following instruction only one student appeared to hold the intended goal conception with the others retaining their preconceptions or various hybrid conceptions. Similar results were obtained with a larger sample in a related study (Roth, Smith and Anderson, 1983). Since the goal of the instruction was by-and-large unfulfilled, the focus of our analysis has been on what went wrong.

While our results are consistent with those reported by Nussbaum and Novick (1983b), there seemed to be another story in our study, one concerned with ways that instruction seemed to go wrong where it might have been otherwise. Among these were:

- Students were often uncertain about empirical generalizations important to the strategy.
- Communication was sometimes hampered by systematic sources of ambiguities.
- The instruction was in some ways attacking the wrong preconception.
- Some important issues were not adequately framed through use of appropriate questions.

While these problems may not have occurred in Nussbaum and Novick's study, it is important to consider carefully the adequacy of instruction and of the particular instructional strategy in making judgments about a generic strategy and its theoretical base.

A detailed report of our analysis is beyond the scope of this paper. Rather we will present here a discussion of some ways teaching for conceptual change can go wrong with illustrations from the study, and discuss their implications for analysis and interpretation of empirical studies of conceptual change. As background, a description of the strategy for the instructional sequence is presented next.

Instructional Strategy

In the introduction we asserted that the sequence from the SCIIS Communities Unit was a conceptual change strategy. This assertion is based in part on the authors' explicit definition and discussion of the SCIIS Learning Cycle but also on our interpretation of the specific teaching suggestions in the Communities teacher guide (Knott et al., 1978).

The SCIIS Learning Cycle

According to the teacher's guide, the SCIIS curriculum is organized around a "learning cycle" consisting of three phases: exploration, invention and discovery. Exploration is characterized as involving students in "spontaneous handling and experimenting with objects to see what happens." The guide points out that "the materials have been carefully chosen to provide a background for certain questions the children have not asked before." It further notes, "During exploration activities you have the opportunity to observe the children and draw conclusions about their existing ideas and understandings" (Ibid, p. xviii). This implies that the exploration phase includes something like the "exposing events." The guide's description of the Learning Cycle does not mention anything like Nussbaum and Novick's "discrepant events", but as will be seen below, the strategy for the sequence under investigation does include and make use of such events.

The second phase of the SCIIS Learning Cycle is invention. This is the introduction by the teacher of a new concept as an alternative to the "preconceptions" which limit students "spontaneous learning." The teacher "will have to provide definitions and terms as new concepts arise. This constitutes the "invention.""(Knott, et al., 1978, p. xviii). Further insight into the intended nature of the "invention" is provided in an article

TABLE 1

SUMMARY OF THE STRATEGY FOR CHAPTERS 3-6 OF SCIIS COMMUNITIES

Anticipated Preconceptions	Strategy Elements			Intended New Conceptions
	Framing Question	Empirical Results	Presented Information	
	Exploration Phase of the Learning Cycle			
	Chapter 3: Looking at Seeds			
	1. What is inside seeds?	Bean seeds have a small, plant-like part inside two large halves and a skin.	The small plant-like part is the "embryo," the two halves are "cotyledons."	Seeds have a small, plant-like part—the embryo—and larger part(s), the cotyledons.
	2. What do the embryo and cotyledon do for the growing plant?			
	Chapter 4: What Seed Parts Develop and Grow			
Plants take in their food from the soil. Water, fertilizer and minerals are food for plants.	3. Which seed parts develop and grow? What do you think each part of the seed does?	Bean embryos develop into plants only when attached to a cotyledon.		
	4. Why did the cotyledon and embryo live when joined?			
	5. Why didn't the cotyledon or embryo grow alone?			
	6. What do the embryo and cotyledon do for the plant?			The embryo develops into a new plant. The embryo develops into a plant only if it is attached to a cotyledon. The cotyledon provides food for the embryo.

TABLE 1 (Continued)

SUMMARY OF THE STRATEGY FOR CHAPTERS 3-6 OF SCIIS COMMUNITIES

Anticipated Preconceptions	Strategy Elements			Intended New Conceptions
	Framing Question	Empirical Results	Presented Information	
	Chapter 5: Do Plants Need Light to Grow?			
Plants need light to live and grow.	7. Do plants need light to grow? When?	Grass begins to grow in the dark and in light.		
	8. Why are the plants in the dark growing so well?			Plants do not need light to begin to grow.
	9. Which plants will survive better? Why?			Plants get food from their seeds (cotyledons)
	10. What does light do for plants?	Grass continues to grow in the light but not in the dark.		
	11. Why did the plants grow in the dark for awhile?			Plants do need light to continue to grow.
	12. Where do plants get the food they need?			
	13. Why did the plants in the dark die and those in the light live when both had the same soil?			Plants do not get food from the soil.
	Invention Phase of the Learning Cycle			
	14. Can you explain the results using the idea of photosynthesis?		Plants use energy from light to make food from water and air.	Plants use light to make food out of water and air.

coauthored by the director of the original SCIS project, Robert Karplus, (Atkin and Karplus, 1962). While students are viewed as able to "invent concepts readily," they are not viewed as likely to be "able to invent the modern scientific concepts..." thus "it is necessary for the teachers to introduce them" (Ibid, p. 47). The authors related this idea to the view that science itself progresses through the invention of new concepts which are not only more powerful and useful, but which change the meaning and interpretation of observations. Thomas Khun's classic articulation of this view (1962) was cited in the article.

Following the invention of a new concept comes the discovery stage. It is important to note that it is not the new concept which is discovered, that is what is invented (i.e., presented by the teacher). Rather, this stage consists of "...activities in which a child finds a new application of a concept through experience" (Knott, et al., 1978, p. xviii). The students have opportunities "to discover that new observations can also be interpreted by using (the new) concept" (Atkin and Karplus, 1962, p. 47). Such activities "strengthen the concept and expand its meaning" (Knott, et al., 1978, p. xviii). They are "essential, if a concept is to be used with increasing refinement and precision" (Atkin and Karplus, 1962, p. 47).

The Instructional Sequence: SCIIS Chapters 3-6

The SCIIS Learning Cycle is designed to move students from preconceptions to new, more scientific concepts and can, therefore, be characterized as a conceptual change strategy. Further, the four-chapter sequence on which our research has focused includes elements similar to the exposing and discrepant events emphasized by Nussbaum and Novick (1982a,b).

The instructional sequence consists of four chapters (3-6) from the SCIIS Communities unit and represents about six weeks of instruction with about three lessons per week. The strategy for the unit is represented in Table 1 as a series of questions, anticipated empirical results of student investigations, and teacher presentations. The major presentation is the invention of the concept of photosynthesis at the end of Chapter 5.

The questions included in the strategy serve several functions, some of which are not readily apparent. The SCIIS teacher's guide does not usually make such information explicit. Our interpretation of these functions are based on observations in thirteen classrooms including instances where the questions have been asked, modified and omitted (Smith and Anderson, 1983). Their functions include:

- encouraging student thinking and exploring their preconceptions about certain phenomena or topics
- establishing the purpose of an empirical investigation
- guiding student thinking about the interpretation of results
- establishing certain issues (rather than others) as the focus of attention
- providing opportunity to apply previously developed concepts and propositions
- confronting students with results which are not easily explained in terms of their anticipated preconceptions (i.e., to make students aware of a discrepant event)
- driving student thinking to consider the underlying explanation for empirical results.

Although not initially apparent, the underlying issue for the sequence is the source of food for plants. Following the student's introduction to the parts of the bean seeds in Chapter 3, Question 2 raises the issue of the function of the seed parts. This focus, carried on through Chapter 4, is crucial since the cotyledon's function of providing food to the embryo is intended to lead into the central, underlying issue of the source of food for plants. Raised again in Question 6 this issue leads the interpretation of the investigation in Chapter 4 beyond the essentially empirical generalization that the cotyledon and embryo need each other for a new plant to grow with which the discussion might otherwise conclude.

Questions 7 and 12 are important in exposing students' preconceptions about the

TABLE 1 (Continued)

SUMMARY OF THE STRATEGY FOR CHAPTERS 3-6 OF SCIIS COMMUNITIES

Anticipated Preconceptions	Strategy Elements			Intended New Conceptions
	Framing Question	Empirical Results	Presented Information	
	Discovery Phase of Learning Cycle			
	Chapter 6: Cotyledons			
	15. What do you think will happen to young bean plants with and without cotyledons placed in the light and dark, respectively. Explain your reasons.			
		Bean plants without cotyledons grow in light, but die in the dark. Bean plants with cotyledons continue to grow in light, but stop growing in dark after the cotyledons shrivel and fall off.		
	16. Which grew better--plants with or without cotyledons?			
	17. How well did plants without cotyledons grow in the dark? In the light?			
	18. What do you think the cotyledons do for a young plant?			The cotyledon provides food for young plants. After the food from the cotyledon is gone, plants need light to make their food.
	19. When do plants need light?			

relationship of light to plant growth and the sources of food for plants, respectively. Question 13 is the point at which the anticipated student preconception that plants get their food from the soil is to be confronted with the discrepancy of plants dying in the dark despite the presence of rich soil. This concludes the exploration phase of the sequence.

Following the invention of photosynthesis as an alternative conception of plants source of food, Question 14 leads to the application of the new concept in explaining the results obtained. Chapter 6 is the discovery phase of the sequence in which the concept of photosynthesis and the food supplying function of the cotyledon are to be applied in predicting and explaining continued growth of bean seedlings with cotyledons removed and left on under conditions of light and darkness, respectively.

Overview of the Study

In many respects the study was similar to that of Nussbaum and Novick (1982b). It was a case study of the use of a particular teaching strategy with a single class of fifth-graders. Our data sources included pre and posttest responses for all students, interviews of target students at five different points, observation notes and narrative descriptions of instruction, tape recordings of all lessons, and transcripts of selected class discussions. One difference was that, in our study, the teacher was an experienced elementary teacher teaching her own students without direct input from the researchers. She was teaching the sequence for the third year, this time using a teacher's guide developed in a related study (Smith and Anderson, 1983) and designed to make the conceptual change strategy more explicit.

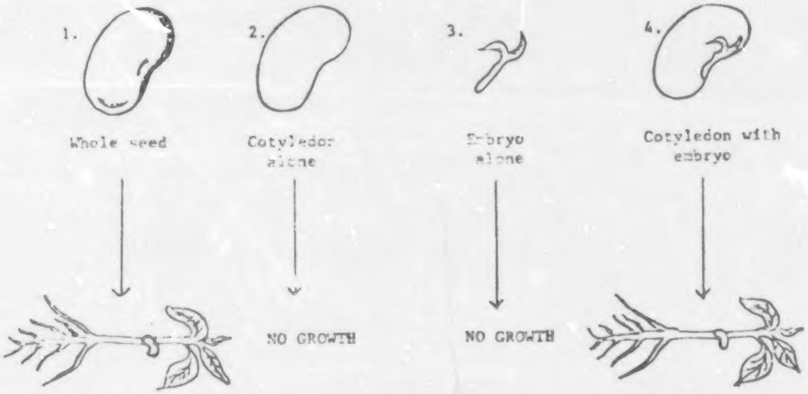
As stated above, the instruction was not very successful in bringing about the intended conceptual changes. About seventy percent of the students incorporated into their coneptions the idea that a plants make food. However, less then twenty percent of them clearly related this to the availability of light. Furthermore, plants making of food was not adopted as an alternative to taking in food from the environment. Rather it was viewed as an additional source. Thus, these propositions tended to be assimilated into the students' preconceptions of what constitutes food for plants with relatively little basic change in those preconceptions. Only one student appeared to have accommodated to the goal conception.

The contrast between these results and the reasonableness of the SCIIS strategy led us to examine the issue of what went wrong. We were led to a number of problems that appear to have general implications for cognitive instruction.

Ways of Going Wrong

Empirical Ambiguity

The instructional strategy depends on certain empirical generalizations. For example, Chapter 4 addresses the issue of the functions of parts of seeds and involves an experiment in which the students attempt to germinate four different combinations of bean seed parts as shown below:



Development of ideas about seed part functions uses the generalization that the embryo develops into a plant only if attached to a cotyledon. This generalization in turn rests on the anticipated results that neither the isolated embryo nor the isolated cotyledons grow, while the embryos with one cotyledon attached and the whole seeds do grow as illustrated. From the standpoint of a trained adult these trends were clear in the students' results. However, making the intended empirical generalization was not a straightforward matter for many of the students.

Two sources of difficulty relate to aspects of what Strike and Posner (1982) refer to as the students' conceptual ecology namely their implicit measurement and observation theories. First, some of the students attended primarily to their own individual set up, ignoring other instances. Their implicit assumption seems to have been that one case is sufficient and agreement among multiple instances is irrelevant. Thus, atypical results obtained by some groups were generalized even when the trend across groups was clearly in the opposite direction.

For example, in some instances the whole seeds did not germinate. The following excerpt from an interview of one of the target students following completion of Chapter 4 illustrates:

> I: What did you think about the whole seed?
>
> S: O.K., it went to 18 millimeters, and 19, 19, 20, 20. I don't know what happened. Well, the whole seed has everything right but it just didn't grow that much.
>
> I: Do you think that some other whole seeds would grow or don't you think that any of the whole seeds grow?
>
> S: I think that maybe some of them would. I don't know.
>
> I: Did some of the other students' whole seeds grow?
>
> M: I don't think so....

This is surprising because, as she implied, this result is somewhat counter intuitive. Furthermore, she had just correctly explained the meaning of points on the class chart

which had color coded dots showing that some of the whole seeds had indeed grown substantially. Apparently, she had not felt it necessary or important to consider the other groups' results. Another indication of this assumption was students referring to atypical individual points on the class graph, rather than to some more central or representative point.

A second aspect of students' implicit observation theories that came into play was judging the significance of differences in the measurements. How much change in the length of the isolated embryo, for example, constitutes "growth". Some of these embryos did grow a few millimeters in length. In comparison to those attached to the cotyledons, however, this growth would generally be considered by our trained adults as negligible. On several occasions, however, students apparently did not apply the negligibility principle and reported that their isolated embryos "grew".

Some of these problems might have been overcome had the teacher put more emphasis on the class graph. That is, she might have pressed the students toward an alternative observation theory. However, the somewhat cumbersome procedure suggested for estimating, recording and connecting average points for each observation of each experimental condition was carried out for only some of the data. The combination of the relatively large amount of time and effort involved and the apparent greater meaningfulness to the students of actual example germination systems led her to deemphasize use of the class graph. Given the nature of the students implicit observation theories, this appears to have contributed to the students continuing to use their original observation theories and the resulting ambiguity in the students' thinking concerning the empirical results.

Ambiguity in Discourse

The ambiguity just discussed in regard to empirical results may tend to arise to some degree in any instruction which relies on first hand inquiry. However, systematic ambiguity can also occur in classroom discourse. In the present case, such an ambiguity exacerbated the empirical ambiguity in Chapter 4. It arose from the possible alternative referents for the terms 'embryo' and 'cotyledon'.

The issue underlying the investigation was the function of the embryo and cotyledon as *parts* of a seed. However, the experiment was set up so that an isolated embryo and an isolated cotyledon were experimental *conditions* as well. Thus, the question, "Does the embryo grow?" is ambiguous. While the isolated embryo conditions did not grow, the embryos as parts attached to cotyledons did grow. Since the function of the embryo as the part that grows is a central issue, there were many opportunities for confusion during class discussions.

Similarly, an important observation made by one of the students and emphasized by the teacher was that the cotyledon (part) was shriveling or shrinking as the attached embryos grew. This was very suggestive of the cotyledon somehow being used up. However, some of the students interpreted these reports as referring to the isolated cotyledon (condition) and tended to disagree. In the process they did not attend to and have the benefit of this important but subtle observation.

Attacking the Wrong Preconception

The SCIS instructional strategy anticipates that students will hold a preconception concerning the source of food for plants, namely that plants get their food from the soil. The teacher's guide also indicates that for the students this "food" is water and fertilizer or minerals, but this is not attacked directly. The point is made that bean seeds in Chapter 4 were germinated without soil and there is an optional activity of growing seeds without soil. The point of exploring the functions of the parts of the seed in Chapter 4 is primarily to provide an alternative conception of the source and nature of food for young plants, the part of the seed referred to as the cotyledon. Finally, the key discrepant event built into the sequence is the determination in Chapter 5 that grass plants survive in the light but not in the dark, *even though both conditions had the same soil.*

While the idea that plants get their food from the soil was common among students in the study, this does not seem to be the core of their conception. The central preconception also seems to be deeper than the idea that water and fertilizer or minerals are food for plants. Fundamentally, food for plants is conceived by the students as whatever materials are needed and taken in by the plants. Furthermore, their notion of food is additive. If the plants are unable to get certain materials from the soil, other materials such as air and even light may be considered as adequate alternatives.

Given the additive conception of food for plants as whatever materials the plants take in, the students could simply add the cotyledon as another source of food rather than add an alternative to what constitutes food. Some of the students saw the cotyledon as an "extra" source of water or fertilizer.

Another consequence of this underlying conception of food for plants was that the students easily escaped the trap represented by the intended discrepant event. Light was simply added as an essential component of plants' food. This preconception also tended to promote what Hewson (1980) calls "conceptual capture" of the concept of photosynthesis when it was invented. Photosynthesis was assimilated to this conception as a process in which light, water and air were mixed together but each substance maintained its own identity. Other students interpreted photosynthesis as the name for this mixture. Asked in Chapter 6 why she thought the bean plants in the dark would continue to grow, a student explained that photosynthesis was light, water and air and that "two out of three isn't bad."

Thus, because the strategy failed to address the students' underlying preconception, few students came to understand photosynthesis as a process in which food is made out of light, water, and air. Even fewer students understood that green plants have no other source of food.

Loose Framing of Important Issues

Many steps in the instructional strategy take the form of questions as reflected in Table 1. In a number of instances we observed problems that could have been lessened by more appropriate use of questions in framing the issues. For example, in Chapter 4 the students appeared to have considerable difficulty relating the empirical results of the investigation to the issue of the function of the seed parts. While part of the problem was probably the uncertainty of the students concerning the empirical results discussed above, another factor was the pattern of questions used to frame the investigation and the interpretation of results. The strategy suggests introducing the investigation with a discussion of the students' ideas about the seed part functions. However, it includes no question requiring the students to use those ideas in predicting what might happen in the germination experiment. In actual instruction, no question which would drive students' thinking to consider the relationship between the results and the students' ideas about the seed parts functions was posed prior to the last two lessons.

When the issue of the relationship between the results and the students' ideas about the seed parts functions was raised in lesson 5, the questions in terms of which it was framed appeared to be inadequate. The teacher first asked the students what they thought the parts' functions were. She then asked for "evidence" to support their views. However, the students' ideas about what would constitute evidence were such that they did not usually see this question as pointing them toward the results of the experiment. Fewer than a quarter of the responses to the teacher's request for evidence in support of the students' views about the seed part functions drew on the results for the four conditions in the experiment. Thus, the question did not appear to match the student's notion of what constitutes evidence.

Given the nature of the students' preconceptions about what constitutes evidence, a question which more tightly structures the students' thinking about the relationship between the experimental results and their ideas about the functions was warranted. In this instance the teacher had not used the questions that had been suggested in the strategy (Questions 4, 5 and 6). In this instance the questions suggested in the strategy do appear to more adequately frame the issue. They first articulate aspects of the results and then require the students to explain why these results were obtained.

Our analysis indicates that the selection of questions is a very crucial aspect of an instructional strategy. In some cases there appeared to be important gaps in the strategy or questions which were not adequate to the situation. In other instances the teacher did not use questions provided in the strategy that appeared superior to the ones actually used. In still other instances the teacher used the indicated question but failed to recognize when student responses indicated predictable alternative conceptions on the part of the student. Such conceptions include the students' implicit observation theories and explantory ideals, elements of what Strike and Posner refer to as the students' "conceptual ecology".

Discussion

The problems we have illustrated indicate that matching instruction to the conceptual ecology of the students is both essential and difficult. Developers must be aware of predictable alternative conceptions and identify appropriate questions and other moves accordingly. Teachers must also be aware of the alternative conceptions and the intended roles of specific questions so that they can recognize indications of students' alternative conceptions and respond appropriately.

The heavy information processing load that this role places on the teacher suggests the importance of incorporating such information into instructional materials. This is not to make the materials teacher proof but rather teachable. Given the best of strategies, the teacher plays a crucial role in the diagnostic use of appropriate questions, in the interpreting of students' responses and taking appropriate actions. In our own work we are exploring the use of text materials (Roth, 1983) and overhead transparencies (Anderson and Smith, 1983) to assist the teacher in appropriate use of diagnosticly and strategicly important questions.

The value of a generic strategy such as Nussbaum and Novick's or the SCIIS learning cycle lies in its prescriptive power. To the degree that it is consistent with the real world of teaching and learning, its use in developing curriculum and planning instruction increases the likelihood that students will learn as intended. While particular strategies might be developed and assessed independently of any explicit generic strategy, the generalizability of such efforts is limited.

While a generic strategy must be sound if its use is to result in effective instruction, a sound generic strategy is not sufficient. A particular strategy may not be an accurate instantiation of the generic strategy or the instruction may not actually implement the strategy. Apart from the issue of fidelity, the particular strategy or instruction may be inadequate in ways that have nothing to do with the adequacy of the generic strategy itself. The examples presented in this paper reflect all four of these possibilities. The models of Strike and Posner (1982) and Hewson (1981) helped identify and interpret these examples and point to other aspects of students conceptual ecology which might be problematic.

In their conclusions,(Nussbaum and Novick, 1982) state:

> In our opinion, the state of the art in cognitive education does not at present offer a widely accepted theory base which could easily facilitate the design of instruction for learning many basic conceptual schemes in school science. p. 20.

While problems such as those described above may not have occured in their study, it is important to consider other levels of going wrong in assessing a generic strategy and its theory base. Such an assessment should probably be based on productivity over time rather than on the success or failure of a single attempt to apply it. While we would not dispute Nussbaum and Novick's statement, we do think that the currently available theory base does provide an important foundation for ongoing development and research.

Nussbaum and Novick (Ibid.) conclude with the following recommendation with which we heartily concur:

> That the growing community of practitioners who are looking at SAF's (Student Alternative Frameworks), extend their studies in the direction of designing and testing new instructional sequences based on principles of cognitive accommodation.

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Misconceptions and Conceptual Change: Philosophical Reflections on the Research Program

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Why should we care about student misconceptions? How will knowing what a student has got wrong help us to teach better? What do we assume about the learning process if we assume that misconceptions are somehow relevant to teaching?

Consider that it is not self evident that we need to know anything about misconceptions in order to teach. Why should we not think of a student's current ideas as rather like material which is stored in a computer's memory. If we don't like what is there and if we wish to replace it with something else, we just write over it. It doesn't really matter what is there currently, since whatever it is, we can just replace it with what should be there. The character of what is being replaced has no bearing on the procedure for replacing it. Why should we not treat the process of teaching like this? Indeed, manifestly many teachers do precisely this. Common practice would suggest that most teachers believe that it is sufficient to acquaint the student with the correct view of the matter, and that whatever views the student currently has on the topic, if any, are unrelated to instruction.

If one is seriously interested in misconceptions, one cannot believe this. Knowing about misconceptions is relevant to understanding teaching and learning only if one believes that a student's current views affect learning, that what a student learns and how is significantly affected by that student's current concepts.

These observations seem to suggest at least two noteworthy implications. The first is that the very act of being interested in misconceptions seems to presuppose a commitment to the basic assumptions of what I refer to as conceptual change theory. The essence of the idea of conceptual change is that learning is not just a matter of gaining knowledge directly from experience or indirectly from words. Learning involves an interaction between experience and information and a student's current concepts. The character of those concepts will determine what is learned from experience or information and how it is understood. Moreover, learning is not just a matter of adding to our current concepts, but of changing or reorganizing them. Again I would suggest that anyone who is seriously interested in misconceptions must believe something like this. If one does not, cataloguing misconceptions may provide joy to those who can take pleasure from the foibles of mankind and relief to those who believe in original sin, but it will have little relevance to teaching or learning.

Second, this view suggests that misconceptions belong to a genre of concepts which might be appropriately thought of as the student's conceptual ecology. A student's conceptual ecology is that set of concepts which affect what the student will find

plausible, comprehensible, or reasonable. They are the conceptual niche in which a new idea must survive.

There are several issues which are worth pursuing. The first of these is the question of what precisely is to count as a misconception. How do misconceptions differ from other components of a conceptual ecology? Is any mistake a misconception? I believe that conceptual change theory has some requirements as to what it would make sense to mean by a misconception.

Second, in what respect are misconceptions of particular interest in understanding how concepts change? And what does conceptual change theory to say about how to deal with misconceptions?

Third, where do misconceptions come from and why do they often seem so resistant to instruction?

In what follows I am going to speculate a bit about how these questions might be addressed and answered. I will deal explicitly with the first and third, and with the second incidentally and in passing. In doing so I am not going to refer to any empirical work on misconceptions or conceptual change except by way of illustration. My purpose here is to try to show how these questions ought to be looked at by someone who takes conceptual change seriously. In a sense, I treat conceptual change theory as specifying the structure of a research program about misconceptions. If this is true, then it should shed some light on the nature of the relevant questions and the constraints on how they can be consistently answered.

I need first to say some very general things about what I mean by conceptual change theory. Two points will suffice. The first is that I see learning as a rational enterprise. The second is that I see conceptual change theory as the modern alternative to the empiricism which has been the main tradition in Western philosophy and philosophy of science for the last several centuries.

On the first point: Much of the way we talk and act about education seems to presuppose an image of the student as a retainer of rather than a processor of experience and information. I believe that this is untrue. I want to suggest that learning is best thought of as a process of inquiry. I do not mean by this comment to argue for some variant of the notion of discovery learning as though I believed that it was somehow a crime to tell something to a student or that students never "really" learn something unless they find it out for themselves. Such views are manifestly untrue. What I do mean, however, is that the task of learning is primarily one of relating what one has encountered (regardless of its source) to one's current concepts. The student who learns something is the one who understands a new idea (which requires it to be located in a semantic sytactical network of concepts), who judges its truth value (which requires

relating the concept to appropriate standards of evidence), and who can judge its consistency with other concepts (which may require alterations in the overall conceptual organization). To "learn" an idea in any other way is to acquire a piece of verbal behavior which one emits to a stimulus. It is not, however, to learn an idea which one understands and can employ in an intellectually fruitful way.

Now I suspect that my current audience will find this view rather attractive. I do, however, wish to note that it does have one rather surprising result. That result is that it is epistemology. not psychology that is the basic discipline for the study of learning. It is after all epistemology which is the discipline which is supposed to describe what counts as rationality. Moreover, learning, conceived as a rational phenomenon, has little do do with "the laws of learning" if indeed there are such things.

Now I do not mean to be overly disparaging of people such as Piaget and many cognitivist psychologists whom I believe have contributed a good deal to our understanding of learning. I am not accusing them of doing work which is not related to genuine learning. Rather I suspect them of being epistemologists in psychologist clothing. The real point of these observations on the division of academic turf is to try to suggest that there is a perfectly good reason why it is that those who are interested in misconceptions often end up being interested in the history and philosophy of science as well. It is not just that the history of science provides examples of misconceptions. More profoundly, the history and philosophy of science provide cases of rational conceptual change and the opportunity to discover what rational conceptual change is like. If, as I have claimed, learning theory is a branch of epistemology, it is not surprising that people who wish to understand how scientific concepts are acquired and how they change are drawn to philosophy. I might add that I also believe that philosophers have something to learn about epistemology by studying learning in a more empirical fashion than they have heretofore been willing to do.

It also follows from these remarks that it is important to have our philosophy of science straight. Someone once claimed that behind every new economic theory there lies a defunct philosophy. I rather suspect that it is even more true that behind most theories of learning there lies a defunct epistemology. Indeed, I believe that the tradition in academic psychology so far as learning theory is concerned has been as sterile as I think it has been because it has essentially been an expression of the epistemology of empiricism. We should then make a few observations about what empiricism is and what the alternatives to it are.

For current purposes, I shall represent empiricism as holding the following:

1)All knowledge originates in experience. The traditional empiricist motto is "There is nothing in the mind that was not first in the senses."

For traditional empiricist theories this was both a claim

about concept formation and about the evidence for our beliefs. More recent versions of empiricism have wished to distinguish between these aspects. We may then appropriately also express empiricism as a theory of evidence.

2)Experience is the sole evidence for our beliefs. Experience is to be linked to our beliefs by subject matter neutral logical rules (sometimes referred to as scientific method) which allow us to decide when experience indicates that we may accept or should reject our beliefs.

3)Knowledge is additive and bottom up. That is, we add to our store of knowledge either by having some new experience, confirming some new idea, or by being able to describe our current store of experiences in increasingly general ways.

The essential difficulty with empiricism was pointed out by Plato in the Meno dialogue. There Plato noted that someone who knew nothing would be incapable of learning anything, for he would be incapable of identifying the truth when he saw it. Let me suggest a simple illustration. Suppose you did not know me or anything about me. Suppose also that I sent you a letter offering you a great deal of money if only you would meet me in Grand Central Station at noon on Monday. I declined, however, to give you any information as to my appearance or my precise location. How would you solve the problem of meeting me? Perhaps your first inclination would be to say that the problem is unsolvable. Since you know nothing about me you have no criteria by means of which you could recognize me. This response is, of course, precisely

Plato's point. A person who was genuinely a tabula rasa would have no way of ever learning anything for he would have no way of thinking about or drawing conclusions on the basis of experience. Of course, if I had offered you a lot of money you might think about the problem a bit more. Perhaps you would ask whether or not you really knew nothing about me. You might, for example, look at my hand writing and see if you could deduce anything about me from how I signed my name. Or you might look at the postmark on my letter to see if it offered any clues.

The moral of this second attempt is also worth pointing out. It is that your ability to learn from an experience is directly related to the quality of the ideas that you are able to bring to judging it. Had you possessed a good theory of handwriting analysis or known a great deal about postmarks, you might have been able to make some progress in discovering me.

Contemporary philosophy of science has turned these sorts of observations into a rather complex view of how scientific concepts are acquired and how they change. Its salient feature is to emphasize the role of current concepts in generating new knowledge. Knowledge does not simply arise from experience. Rather, it arises from the interaction between experience and our current concepts which occurs in problem solving. Some particulars of this view are:

1)Problems are generated by current concepts. Intellectual problems do not simply emerge from experience. They are, rather, more likely to be the product of a discrepancy between the intellectual expectations generated by our current concepts and our actual current capacity to explain experience in terms of these concepts.

2)Solutions to problems are judged by means of current concepts.Proposed solutions to problems need to do more than simply explain or predict the phenomena. They need to do so in ways that current concepts regard as a successful form of explanation and in ways that are consistent with other knowledge.

3)Concepts are a precondition of experience. Seeing is something we do with ideas as well as senses. We cannot see what we cannot conceive. Moreover, people who approach the world with different concepts will see it differently.

4)Current concepts are a product of a history of conceptual development. Current concepts are a product of a history of attempts to understand the world and the modification of concepts in light of their inadequacies. Current concepts may not be perfect, but they are rarely arbitrary or altogether unreasonable. There is a reasonable presumption concerning views that are extant in the scientific community that they are received because they have had some success in accounting for some range of experience, they have survived over their competition and they are products of some degree of testing and refinement. This does not guarantee their truth or their continued adequacy. It does, however, make them objects of respect which should not and will not be lightly dismissed.

Recall that I claimed that epistemological views are the foundation of views of learning. Consider, then, how empiricism and conceptual change theory affect our view of learning generally and our view of misconceptions in particular.

The crucial difference is that empiricism gives us no reason why we should consider current concepts as relevant to learning. Empiricism believes that concepts are taken directly from experience and that current concepts are unnecessary to learning. Views which emphasize conceptual change, however, assume that the student's ability to learn and what will be learned are highly dependent on the concepts which can be brought to the experience.

Empiricists are also inclined to see learning as additive. Learning is a matter of accumulating experiences, rather like a squirrel acquires nuts, and building generalizations on them. Conceptual change views, however, are likely to emphasize the transformation of concepts in the process of learning. New ideas are not merely added to old ones, they interact with them, sometimes requiring the alteration of both.

Concerning misconceptions empiricists are likely to see them as generalizations drawn too quickly from too narrow a range of experience. Empiricism does not, however, provide much reason to treat misconceptions as problematic for instruction except perhaps as possible sources of bias. They are not, however, likely to be seen as part of a student's conceptual ecology and thus as sources of distortion of other information and ideas. They are more likely to be seen as rather like a faulty byte in a computer's memory, something that is easily erased or written over.

Conceptual change theories, however, are likely to see misconceptions as emerging from some interaction between experience and other concepts the student has (perhaps themselves misconceptions). They are also likely to see misconceptions as highly problematic and as crucial phenomena for teaching and learning. The reason is that misconceptions will be seen as part of the student's conceptual ecology which will thus function as part of the student's cognitive repertoire for understanding and judging other concepts. Moreover, misconceptions will be seen as fitting into a student's conceptual ecology and thus as not easily written over. As part of a conceptual network, misconceptions will be maintained both by their ability to distort or reject incompatible information and by the support that they draw from other concepts in the student's arsenal. Conceptual change theory thus sees misconceptions as crucially important phenomena having both the ability to distort further learning and as themselves highly impervious to instruction.

With this as background, we can now move on to the first of our central questions. Does conceptual change theory provide any help in understanding what it would make sense to mean by a misconception? I think the central point to make here is that a misconception ought to be the sort of thing that appears to have a structural role in how students deal with some range of phenomena. Misconceptions are, therefore, not just mistakes, they are not even persistent mistakes, rather they are mistakes which play an important role in a student's conceptual ecology.

Consider the following illustration. When he was at Cornell a few years ago Joseph Nussbaum showed me some of the data he had collected on children's views of the organization of the solar system. In one case a child had drawn a picture of astronauts going from the earth to the moon. He showed the rocket going around the moon and landing on the other side which he represented as somewhat flattened. Now what is the misconception here? Certainly there are a number of mistakes. The other side of the moon is not flat. But I would suggest that this is not the misconception. Rather what I suspect to be the misconception is the assumption that there is an absolute up and down. The child has put his astronauts on the top of the flattened moon to keep them from falling off. A brief perusal of Yossi's collection of drawings will quickly suggest both how common this idea of an absolute up and down is and the extent to which children are not only willing but able to redesign the cosmos so as to render their cosmology consistent with absolute up and down.

The point:From a conceptual change view, one is not simply interested in generating a catalogue of errors. There are some kinds of mistakes which are nothing more than that. They are simply things that the person has got wrong. They can be corrected by providing accurate information. There are others which are generated mistakes. That is, they are mistakes which a person makes because that person believes other things from which they

follow or because they are necessary in order to reconcile a piece of data with a mistaken assumption. These two groups are not very interesting, however. In the first case they are not interesting because they are the sorts of errors which can be written over. They do not require a special kind of instruction to handle them. The reason is that they are not generated by something else in the student's cognitive structure. They are accidents and can be dealt with with nothing more complex than a statement of the truth.

Generated errors are more interesting. They are the handiwork of genuine misconceptions. But they are not the crucial phenomena for the simple reason that they are generated. They are unlikely to be the sorts of things that can be written over since they are the effect not the cause. If one succeeds in persuading the student that they are incorrect, the student is likely to respond with another error that serves the same role or solves the same problem in the student's conceptual system. If the student who comes up with a flat earth in order to keep the people from falling off is denied that solution by a teacher the student may simply conclude that all of the people on earth live on the up hemisphere. If the student is denied that account, he or she will find another or even worse conclude that science is not supposed to yield a consistent view of the world.

What then is there to mean by a misconception? I would suggest that a misconception should be regarded as an assumption that is structurally important in the student's belief system. It is something that generates mistakes. It is a piece of the student's conceptual ecology that serves to select or reject other ideas or to render them more or less intelligible.

A few caveats may help to sharpen this idea a bit.

Note that this view of what a misconception is and the theoretical role misconceptions play in a view of learning differs from the role misconceptions might play in other theories. I would suppose, for example, that a Piagetian would find misconceptions interesting because they would be seen as the footprints of a certain stage of development. Certain responses to conservation problems, for example, are signs that the student has not achieved the ability to perform formal logical operations. For a Piagetian, then, misconceptions are not important either because of their importance as scientific concepts or because they themselves play a key role in a student's cognitive structure. They are important because they are clues to the cognitive capacities possessed by students. These cognitive capacities can be described in a formal, subject matter neutral way and are themselves the key pedagogical phenomena in that they may place limits on what may be understood at a given stage or in that they specify how a given topic may be taught so as to be consistent with a student's current capacity for representing ideas.

In the view of misconceptions I have just sketched, however, misconceptions themselves are treated as the cognitive structures that generate additional mistakes. Misconceptions, thus, play a role in the theory I am describing which is akin to the role

played by the cognitive apparatus Piaget uses to describe a person's ways of thinking at a given stage.

I am unclear as to whether the general theory of conceptual change involved in this discussion is inconsistent with Piagetian stages. It does, however, at least differ from Piaget in the very important respect that substantive concepts, not just operations, are looked at as being cognitively important. The view of misconceptions I have sketched indicates that so far as science instruction is concerned, substantive concepts--misconceptions or otherwise--are more important for understanding science instruction and science learning than are stages of cognitive development.

A second point worth noting is that this view of misconceptions suggests that those misconceptions that are important to science may not necessarily be scientific misconceptions. That is, this view of misconceptions is interested in those ideas which tend to dominate or influence what is believed about scientific matters. It may, however, turn out that many of the concepts that influence scientific belief for good or ill are not themselves scientific concepts. Einstein seems to have been influenced by theological considerations. Certainly Newton and Kepler were. There is also much discussion concerning the role of culture or politics on the formation of scientific belief. Some ways of thinking about natural phenomena may be lurking in the conceptual organization of the language we learn as children. Modern intellectual life tends too much to present ideas in disciplinary packages with the result that we often do not to think to look for relevant pieces of a conceptual ecology outside of the discipline we are interested in. History suggests we are naive in this.

Among my favorite places to shop for the sources of scientific error is epistemology. George Posner and I have collected some evidence that indicates that many undergraduates are not exactly overburdened with a need to have what they learn in science classes be consistent either with other scientific ideas or with their own experience. Somewhere they have gotten the idea that science is allowed to be paradoxical and is not supposed to have anything to do with their everyday experience. This "view" seems to have a substantial effect on the science learning of those students who exhibit it.

Generally, I suspect that if we are interested in understanding the errors our students make in matters scientific, we must not be afraid to look for the sources of these errors outside of the official domain of science.

Now this way of putting the matter suggests a terminological difficulty. It would seem to follow, if I am correct, that there are not just scientific misconceptions (or that misconceptions are not primarily scientific). We must also be willing to talk about epistemological misconceptions, linguistic misconceptions and, heaven forbid, theological misconceptions. Something seems odd in such talk. I suspect the main problem is that in those areas where we are less sure than we seem to be in

the natural sciences that we know what is in fact the right view, it is harder to talk about misconceptions. In an area such as philosophy where reasonable people are inclined to disagree about almost everything--even very basic philosophical matters--it is question begging and therefore offensive to label some particular view a misconception. To do so is to assume that the holder of the view is incorrect and that the only real problem is to diagnose the source of the difficulty.

Let us grant the objection. It is probably better to save the word "misconception" for those viewpoints where the presumption that what the student believes is clearly wrong is a justified presumption. For the most part, therefore, when we talk about student misconceptions, we will be talking about scientific concepts that the student holds that are 1)non-controversially wrong and 2)the generators of other mistakes. This way of talking will, I believe, prove most convenient, most theoretically illuminating and least presumptive. But let us not forget that misconceptions may very well have sources outside of the domaine of science.

This leads me to the last topic that I wish to address. Conceptual change theory seems to me to have some obvious implications about where misconceptions come from. Specifically, it suggests that they do not derive from experience, at least not in any very simple or direct fashion. Let me first characterize the view I wish to reject and then give you some reasons for rejecting it. I shall label the view I wish to reject the "experience wears its misconceptions on its sleeves" theory. The theory holds that misconceptions are strongly rooted in experience. Misconceptions are simply what any reasonable observer would conclude given a limited but typical range of experience. On this view the answer to why people hold the misconceptions they do is that the world looks that way.

In a recent article in the Scientific American entitled "Intuitive Physics"(April 1983), Michael McCloskey argues quite persuasively that many students hold views of motion that are quite similar to the medieval impetus theory. He then goes on to account for these theories in the following way:

> The striking similarity between the views of the medieval philosophers and those of our subjects suggests the impetus theory is a natural outcome of experience with terrestrial motion. It is easy to see how experience could lead to the basic idea that objects are kept in motion by an internal force that gradually dissipates: in most circumstances an object that is in motion keeps moving for some time, but it eventually stops. What is difficult to understand is why people develop incorrect beliefs about the trajectories of moving objects, beliefs that apparently conflict with everyday experience. Why, for example, do people come to believe that carried objects fall straight down when they are dropped?
>
> A possible answer is that under some conditions the motion of objects is systematically misperceived....The

> misperception may be the source of the corresponding belief.... (p.127)

McCloskey then goes on to describe several experiments in which students misperceive something.

Note the structure of this passage. First, McCloskey provides a quotable version of the "experience wears its misconceptions on its sleeve" theory. He then notes a difficulty with this account. There are many misconceptions which seem flatly contradicted by experience. This problem is solved, however, with the suggestion that people often misperceive. One should not, it seems trust the sleeve of experience.

I would suggest that the account is implausible. If people in fact misperceive, as I firmly believe, then this misperception itself requires an account. Those familiar with the philosophy of science literature from which the conceptual change account of misconceptions is derived will recognize that there is a handy account available. It is that "experience is theory imbedded." People tend to see what they expect to see or what their theories tell them they should see.In this account it is the misconception that accounts for the misperception and not the other way around.

Why reject the "experience wears its misconceptions on its sleeve" account? I would suggest two reasons. The first is that the view has no viable account of why it is that people acquire misconceptions when there seems not to be a body of obvious experience from which they are derived and why they maintain them when they are contradicted by both experience and teaching. The view is a plausible account of neither the source nor the resilience of misconceptions.

Consider a case. Human beings once widely believed that the world was flat. Children often still do. Why? The simple answer is that it looks flat. But this seems clearly wrong. First, unless one has the misfortune to live in Kansas, it does not look flat. Of course, it does not exactly look like a round ball either. But why do people seem to want to impose a flat shape on the ambiguous data rather than a round shape or some other shape? Why do they wish to do this when there seem to be numerous observations (such as the curvature of the ocean or any sizable lake) that provide evidence that the world isn't flat? I would suggest that the answer is not experience. A more plausible account is that the earth is flat theory seems required by some other belief such as that of the absolute character of up and down. The world does not wear flat on its sleeve. Instead, some concept conceals it in its logical pocket.

The second reason is that the view is inconsistent with the grounds for being interested in misconceptions. I have argued that misconceptions are only of serious pedagogical interest if one subscribes to something like a theory of conceptual change. It is conceptual change theory rather than empiricism that explains why it is that misconceptions cannot simply be written over and indicates something of their importance in learning. Now a view that subscribes to a conceptual change theory of how misconceptions work and why they are of interest and also

subscribes to the "experience wears its misconceptions on its sleeves" account of the origins of misconceptions is simply inconsistent. It has accepted a conceptual change account of most learning phenomena, but an empiricist account (and a simplistic one at that) of the learning of misconceptions. At the very least, we are owed some explanation of why we should accept a separate theory for the learning of misconceptions than the one we are given for why they are worth knowing about.

This argument can be put in a slightly different way. Misconception research makes the most sense within a certain research program. This program emphasizes the role of prior concepts in learning--the role of conceptual ecologies in the selection and rejection of new ideas and in their comprehension. This research program indicates that when we wish to account for how some piece of learning takes place or fails to take place we look at the learner's current concepts and how they interact with one another, with instruction, and with experience. It would be odd to say the least to work within this research program when understanding the point of misconception research and to abandon it when trying to understand how misconceptions are learned. If we are to have a consistent research program for misconceptions we will either need to know how misconception research has a point on empiricist assumptions, or we shall have to abandon the "experience wears its hypotheses on its sleeves" account of where misconceptions come from.

Consider then two important implications of these observations. The first is that misconception research will eventually take us far from the domain of science. We will discover that the concepts that select for the misconceptions that our students commonly hold are not other scientific concepts. They will inhabit domains from religion and politics, to language and music. We will find that a society's climate and its economic system will generate concepts which will affect how scientific ideas are understood. Unless we are willing to look in these places we will not come to understand the etiology of misconceptions well. Cross cultural studies of misconceptions may prove illuminating here.

The second point is that unless we are able to track down the etiology of misconceptions, we will not be successful in dealing with them. We already have much evidence to suggest that misconceptions are fairly resistant to instruction. Why? One suspects that the reason is that they are maintained by other concepts in the student's conceptual system. Misconceptions live in a conceptual ecology. We will not extinguish them unless we understand the structure of that ecology.

Consider by way of example one study that seems to me to exemplify the approach to misconceptions to which my argument leads.

Hewson and Hamlyn have done a study investigating conceptions of heat held by Black South Africans. (Marianan G. Hewson and Daryl Hamlyn, "the Influence of Intellectual Environment on

Conceptions of Heat" AERA 1983) They begin by noting that research on Western students indicates that many students hold something very much like a caloric view of heat. They then address the question as to whether members of the Sotho people of South Africa also have such a view. Their study includes a description of the role heat metaphores play in Sotho culture. The study concludes with the claim that members of the Sotho culture are less likely to hold a caloric view than are Westerners and that they do frequently exhibit something close to a kenetic view. They suggest (with suitable caution) that cultural and linguistic factors should be investigated as possible explanations of these differences. Their own formulation of the conclusion is worth quoting.

> The results concerning the metaphorical heat concepts substanciated the anthropological literature and showed that a particular heat metaphore was prevalent which may be seen as based on experiences of living in a hot, arid part of the country. According to the metaphore, the condition of being hot is thought to be bad (i.e. unhappy, sad, sorrowful, tired,etc.) and involves a conception of agitated blood. While no direct causality can be attributed to this fact, it would appear that there is an inferential "logical fit" between the metaphore and the high frequency response for prekinetic conceptions. (p.18)

The study is a fine example both of how cultural assumptions can structure scientific intuitions and of how to proceed to find this out.

I shall conclude with five suggestions for research .

1)Cross cultural studies can be quite revealing concerning the sources of misconceptions. Looking at the conceptual ecologies of non-Westerners can be a friutful way for us Western fish to see our conceptual water.

2)In any study of misconceptions, it is important that we attend to the collection of appropriate demographic variables. That some misconception varies according to race, SES, or sex can provide clues to the origins of misconceptions.

3)We need to pay attention to the student's epistemology. George Posner and I have collected some evidence that what students believe about the nature of knowledge makes a difference in their willingness or ability to respond to instruction.

4)We need to examine the ordinary language and the culture's stock of metaphores and analogies to see how scientific topics are represented in them. We may often have little further to look for the sources of misconceptions than how we talk.

5)We need to look at the structure of the institutions in which we teach. George Posner and I have also found that many students approach their science courses with a distinction between the world of ideas and the real world which easily leads them to discount contradictions between theory and experience. This sort of student Platonism may well have its roots in the institutional form of formal education itself. To understand the conceptual ecologies that students bring to science we may have to understand the hidden curriculum of the classroom better.

Student Perceptions of Evidence and Interpretations

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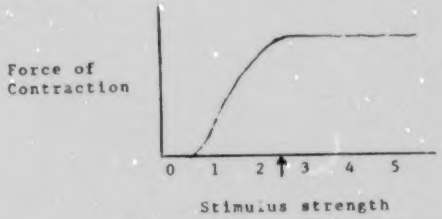
Most of the literature on student misconceptions in science focuses on specific content topics (e.g. electric circuits, laws of motion, Mendelian genetics). Our experience in a General Biology Program has indicated another category of misconceptions regarding the processes of science (5, 8). In the program at West Virginia University strong emphasis is placed on processes such as interpretation of data, the derivation of concepts from evidence, identification of assumptions, drawing conclusions, and making predictions. Such activities are highly complex and represent biology as a logical, problem-solving activity as well as an exercise in the memory and recall of terms and definitions.

One point which is given particular emphasis is the relationship between evidence and interpretations. As scientists, we are keenly aware of the distinctions between the two. As shown in Table I, evidence and interpretations differ with respect to the degree of confidence that can be placed in them, to their sensitivity to assumptions, and to their permanence. In addition, observations can be gathered independently, while interpretations must proceed from evidence.

Many of our students, however, do not make these qualitative distinctions, and indeed, even exhibit some difficulty distinguishing evidence from interpretations after extensive practice. For instance, in Problem 1, students are required to evaluate the three statements regarding the graphical data. Even without knowing the muscle physiology involved in the problem, it should be apparent that statement C is only a description of the observations while statements A and B are attempts to interpret the observations. However, 57% of the 50 students tested with this problem claimed that C was an acceptable interpretation.

Problem 1

The data shown in the graph below were obtained from a whole muscle stimulated with electric shocks of increasing strength.



Three students (A, B, & C) observed these data and made the following statements.

- A. Different muscle cells comprising the muscle have different thresholds.
- B. All muscle cells comprising the muscle are contracting at stimulus strengths greater than the arrow (↑).
- C. The force of contraction increases gradually reaching a maximum at stimulus of about 2.5.

Which of these statements would be the best interpretation(s) of the data?

In Problem 2, students were tested on the effects of repetition on the confidence in each statement. Since statement C is the observation, obtaining the same results would increase one's confidence in the accuracy of the observation, but not affect the confidence placed in the interpretations. Again, 57% of the students maintained that confidence in A and B would be increased.

Problem 2

Suppose the experiment in Problem 1 were repeated 10 times, and every time identical data were obtained. This would increase your confidence in which of the statements in Problem 1?

Such questions would seem to represent relatively simple applications once the characteristics of interpretations and evidence are understood. Nevertheless, many of our students exhibit persistent difficulty.

More detailed insight into students' difficulties is provided by student responses during class discussions and individual tutoring sessions. In our program discussion plays a central role in the instructional process. Students are provided evidence and required to suggest and argue for interpretations, recognizing that several interpretations may be possible, and to suggest further experiments which would test these interpretations. Students are guided to provide detailed arguments or lines of reasoning which will relate the available evidence to an acceptable interpretation. Frequently, however, they comment, "You are the teacher, it's your job to tell us the answer." Many show a disturbing tendency to give responses which they know are true about the particular topic but which do not follow from the data presented. On other occasions students seem to regard evidence as superfluous; as one student remarked, "If you know what is true, why worry about the evidence?" When students are led to recognize interpretations which appear to contradict what they believe to be true, they feel they have to "throw away everything they have learned".

Such students appear to want to start with an interpretation, either one the "know" or one which is provided by the instructor, and use it to explain any observations of data. Granted, we frequently use such a deductive approach to explain new observations. Students, however, will often use existing interpretations to explain the very observations or evidence which were originally used to derive the interpretation, without recognizing the circular nature of their arguments.

These students appear to operate using what Arons (2) has termed "backwards science", or scientific reasoning being used in a backwards way: data being used to justify pre-existing interpretations or conclusions, rather than interpretations being generated as explanations of data. Somehow, students appear to have the notion that conclusions are "known" before any data are available. Indeed, many instructors and textbooks may foster such perceptions by giving "answers" at the start of the lecture or beginning of a chapter and then proceeding to "prove" the concepts instead of beginning with observations and using them to develop the concepts. Arons further indicates that such procedures "carry for the student the clear implication that there existed an a priori reason for the phenomenon - a reason that the scientist had long ago discovered and that the student himself might also have known had he had the proper revelation".

Although it is tempting to attribute these student difficulties to conditioning by prior instruction, our experience suggests that the causes may be more fundamental. Attempts to understand these difficulties in more basic terms have led many science instructors to examine scientific reasoning ability in relation to intellectual development. One theory which may provide valuable insight into these difficulties has been developed by William Perry to describe intellectual growth in college students (6, 7). Perry and his colleagues studied intellectual development in Harvard undergraduates and perceived sequential changes in students' views of knowledge during the college years. Students were found to progress from dualistic views (Perry's positions 1, 2, and 3), considering knowledge in simple right-wrong terms, to multiplism (Perry's position 4), characterized by the acceptance of multiple views but the inability to evaluate these different views. Further progress led to relativistic veiws (Perry's positions 5 and higher) of knowledge as relative and evaluated according to context. A more detailed description of the positions is provided in Table 2. These positions are conceptualized as relatively stable points along the developmental continuum, but peer interactions and academic experience seem to favor a re-evaluation and revision of views toward more relativistic positions (9).

One of us (1) has previously argued that students at position 2 would expect the instructor to provide all interpretations since only authorities supply answers. Indeed, it probably does not occur to such students that they can make interpretations and they view any instructor who requires students to do so as a poorly qualified authority (Table 2). Moreover, they would make little distinction between interpretations and observations and would consider both to be information provided by authority.

At position 3 students work hard to "find the answer" and are clearly dualistic in the sense that they believe that right and wrong answers exist in all cases. For these students, a variety of interpretations may seem puzzling but they accept the variety since we "don't know the answer yet" (Table 2). However, once the answer is known, they would likely consider an examination of the supporting evidence as unproductive. Recall the student described earlier, "If you already know the truth, why worry about evidence?"

At position 4 students would likely deal with interpretations as opinions which require no supporting argument. Even if they did provide a rationale, they would probably not critically evaluate their argument relative to others ("Everyone has a right to their own opinion").

Our research has shown that Perry positions 2, 3, and 4 represent the great majority of our students, at least at the freshman level. The data shown in Table 3 were obtained from 100 freshman students selected randomly from those enrolled in a general biology course. Note that 76% of these students are at or near position 3 while 6% are at position 4 or higher and 18% are at position 2.

With results such as these, it is not surprising that students experience difficulty, become frustrated or even antagonistic when attempting to deal with science as a process of evidence leading to interpretations. Considering the way they view knowledge and the means they use to make meaning of the world around them, in terms of science or otherwise, their problems are much more understandable.

Change in developmental stage is slow, but efforts to foster such change have been productive (4). If misconceptions are related to a student's developmental stage, then one would expect that changes in misconceptions would also be slow. We have found this to be so but have also shown that instruction which addresses students' views of knowledge leads to significant improvement (8).

Conceptualizing misconceptions in terms of a student's developmental stage offers some promise of understanding their difficulties in fundamental, theoretical terms. Perry's theory is, however, quite general and may be most valuable as a background for framing more specific hypotheses about the causes of misconceptions. Our experience and investigations suggest that such an approach would be productive at both the theoretical and applied levels.

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Table 1

Relation Between Evidence and Interpretations

Evidence (Observations, Data)	Interpretations
Only one, or one set, accepted as valid under given conditions	Two or more may be accepted as valid from the same set of observations
No argument required to establish validity (other than justifying techniques)	Logical argument required
Generally accepted by others if repeatable	Open to question and reinterpretation
Relatively high degree of confidence placed in repeatable observations	Relatively less confidence
Relatively permanent under given conditions	Subject to change as new evidence becomes available
Confidence increased by repetition	Confidence increased by a variety of tests leading to same interpretation
Less sensitive to assumptions	More sensitive to assumptions

Table 2

Perry Scheme of Development

(Perry, 1970; Hefferman, 1975)

Dualism

Position 1 - Knowledge and values are viewed in polar terms of we-right-good vs. they-wrong-bad. Authority sets truth and is not questioned.

Position 2 - Diversity is recognized but is explained as unwarranted confusion and/or poorly qualified Authority. Good and bad Authorities exist.

Position 3 - Diversity and uncertainty are recognized as extensive but are viewed as cases where "we don't know the answer yet." The students are willing to work hard to "find the answer for themselves" if it is not provided by Authority.

Multiplicity

Position 4 - Uncertainty and diversity are seen as legitimate and non-temporary. Such diversity is acceptable since "everyone has a right to their own opinion."

Relativism

Position 5 - All knowledge and values (including authorities') are seen as contextual and relativistic. Students view themselves as decision-makers responsible for their own learning and progress.

Position 6 - 9 - Students develop commitment to personal values and goals.

Table 3

Distribution of Students as a Function of Perry Position (N = 100)

erry* ating	Number of students with indicated rating
556	1
---	--
445	1
444	1
344	3
334	9
333	42
233	25
223	12
222	6

ach student was rated on the basis of his/her response to n essay question on evaluation of their educational experience. rating is reported as 3 digits. For example, a 334 indicates hat a student is primarily at position 3 but shows some haracteristics of a position 4.

IDENTIFICATION OF MISCONCEPTIONS IN GENETICS AND THE USE OF COMPUTER SIMULATIONS IN THEIR CORRECTION

by

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1. INTRODUCTION

Genetics is accepted as an important and relevant component of courses of study in the biological sciences. However, reports from U.S.A. (Stewart 1982, Tolman 1982), U.K. (Longden 1982) and Australia (Hackling and Treagust 1982) have identified student learning difficulties relating to both content and procedures of genetics.

A principal aim of the genetics component of biology courses is to develop in students an understanding of and an ability to apply genetic principles. The learning experiences to which students are exposed in pursuit of this aim include inter alia laboratory activities, text book readings and problem solving tasks. The understanding of genetic principles achieved by students is commonly assessed in part or whole by measurement of their performance on problem-solving tasks administered in a "pen and paper" mode. While students who are consistently unable to solve genetics problems on a particular topic can be readily identified as lacking understanding of some or all of the relevant genetic concepts, the converse does not necessarily apply. Some students can obtain the correct answers to problems where that outcome does not reflect meaningful understanding of the relevant concepts. This situation can occur particularly when the "style" of the test problem replicates that of the problems comprising part of the student's previous learning experiences.

Non-meaningful or rote problem solving by genetics students has been reported by several investigators. For example, Longden (1982) has identified "the use of stereotyped procedures for solving problems"; Walker et al. (1979) found that "some students can... solve problems when the data and methods are replicas of familiar problems, but... cannot develop solutions when required to apply abstractions and reasoning to unfamiliar, but related genetics problems"; Stewart and Dale (1981) concluded that "students can become proficient at obtaining correct answers without knowing why they are right".

It follows then that "correct" answers to genetics problems do, in some instances, reflect meaningful learning, but in other cases, a "correct" outcome reflects rote learning and results from application of learned rules. In the latter case, it may be asked whether the lack of meaningful learning is intrinsic to the concept and due to a high level of difficulty of the concept concerned, or whether it is a result of other factors, such as limitations or biases in the learning experiences of the students which favour application of learned rules.

Exposure to the operation of chance is an important element of the learning experiences for students of genetics, since key components of transmission genetics, such as allelic segregation and gene assortment during gamete formation, are probabilistic in their outcome. An understanding of the role of chance in these processes is fundamental to Mendelian genetics and is required by students in order that they may meaningfully interpret data and predict the outcome of crosses. The action of probabilistic processes is

inherent in and commonly expressed as one of the classic Mendelian ratios which describe the expected outcome of certain crosses, such as the 3:1 phenotypic ratio of a monohybrid cross and the 9:3:3:1 ratio of a classic dihybrid cross.

This paper reports an investigation into the concepts of probability held by genetics students in two contrasting contexts, namely a traditional"genetics" context and a "real life" context. The paper also describes some outcomes of the use of a computer simulation as an extension to traditional learning experiences of a group of genetics students.

2. BACKGROUND TO THE STUDY

Incidental observations from earlier work indicated that some students regard genetic ratios as deterministic rather than probabilistic. A study of the strategies used by students of genetics in hypothesis testing involved the tape-recording of students as they "thought aloud" (Kinnear, Martin and Novak 1982). The following are excerpts from these tapes. Student comments are denoted by 'S' and remarks by one of investigators are denoted by 'I'.

A student using the genetics simulation CATLAB (Kinnear 1982) was attempting to identify the genotype of a cat that he postulated was heterozygous. He set up a test cross and obtained a litter of four kittens, two of which were black and two of which were gray:

S: That's nice.. half and half

I: Would it have worried you if the ratio had been say 3:1 in those four kittens?

S: Well.. I would have had to change the genotype of this cat. 'Cos this is a test cross you see... If I was getting something that's not half and half there would be another.... there would be.... homozygous... I would have rejected the fact that this cat is heterozygous. I would have worked on some other genotype that could be explained by the results."

Another student set up a cross of two black cats and obtained a litter of four kittens, three black and one gray.

S: Just what I was hoping.

I: What would you have done if you had got four black kittens?
S: Start screaming.
I: How many children are there in your family?
S: Two, a boy and a girl.
I: Do all two-children families consist of one boy and one girl?
S: No.... but that's real life.

It is of interest to record that the student then repeated the cross and this time obtained six kittens, all of which were black!

The excerpts above came from two Bio281 students at Cornell University. A similar reliance on classic genetic ratios without regard to the number of offspring involved was also seen in a sample of students from the other side of the globe.

This group of students (N=189) comprised students who had successfully completed year-12 high-school studies in general biology including a component of genetics in 1982, and who, in 1983, had entered College and were enrolled in first-year Biology A01 or A02 at Melbourne College of Advanced Education. The students were given two short questionnaires during the first two weeks of the academic year - a "real world" quiz and a "genetics" quiz. About half the students completed the genetics quiz first and then, about a week later, attempted the "real world" quiz; the remaining students did the questionnaires in the reverse order.

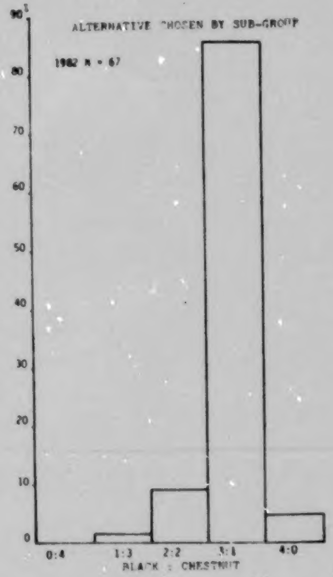
Appendix 1 gives the relevant items. In subsequent discussion, these items are referred to as the "drug" problem and the "horse" item. The table below shows the percentage of students choosing a given number of alternatives:

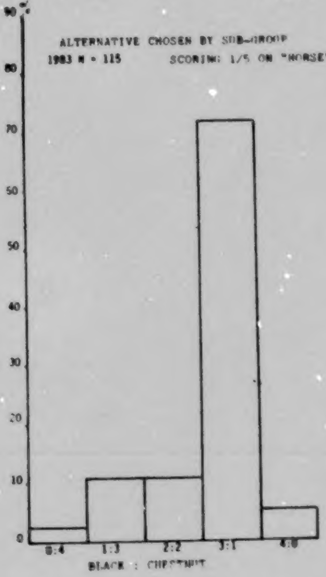
NUMBER OF ALTERNATIVES	0	1	2	3	4	5
"DRUG" ITEM	2.8%	15.8	5.0	5.0	2.1	69.3
"HORSE" ITEM	9.0%	60.8	8.5	3.7	3.2	14.8

The mean number of alternatives selected for the "drug" item was 3.96 (s.d.= 1.86), while the mean number of alternatives chosen in the case of the "horse" item was 1.76 (s.d.=1.56).

These results suggest that the majority of students (69.3%) recognise that chance was operating in the process of capsule formation and that all five outcomes were possible. In contrast, the majority of students were incorrect on the "horse" problem, and of this sub-group, nearly three-quarters chose only one alternative from the five stated.

Of those students who chose one alternative only for the "horse" problem the majority selected the 3 black:1 chestnut alternative. This is shown in the histogram below, and may be interpreted as indicating that students are rotely applying the "rule" that the mating of two heterozygotes produces offspring in the expected ratio of 3:1, without regard for sample size. A similar study carried out with a group of students in the previous year also showed that the majority of students (69%) also chose one alternative only, and that of this sub-group, 85% selected the 3 black:1 chestnut alternative. These data are shown in the histogram below.





The significant difference between the students' responses to the "drug" and the "horse" items suggests that the perception and understanding of the operation of chance is for many students dependent on the context in which they are operating, that is, whether they are solving a genetics problem or whether they are considering a "real world" phenomenon.

While the problems represented by the two items both involved an understanding of probability, the processing required for the "horse" problem involved an implicit understanding of other concepts such as heterozygosity. However, the results of another item included in the questionnaire showed that student performance was not hindered by this requirement, since nearly all students (95.2%) correctly recognised that each black foal was heterozygous.

The tendency of students to apply rules in a rote manner in genetics problem solving was also revealed by the results on another item included in the genetics test. This item was as follows:

> In budgerigars, green (G) is dominant to blue (g).
> A green budgie was crossed with a blue budgie and
> 8 fledglings were produced. These offspring were
> green and blue in the ratio of 3:1.
> *This result proves that the two parent birds
> are heterozygous.

Students were required to indicate either true(T) or false(F). More than half (52.4%) of the student sample selected the true alternative.

This result should not be interpreted as indicating that the majority of students in the sample lacked the ability to assign genotypes and identify outcomes from simple crosses. The result is a further indication of the strong influence of a given ratio on the mental processing of many students when 'solving' genetics problems, and the ability of this ratio to evoke a rote response from students. This was apparent when students who had responded incorrectly were asked to rework the problem and were given the added direction to write parental genotypes. One student immediately commented:

> S: Of course it's false... it's nonsense.. the blue bird can't be heterozygous.

Another student when asked why she had responded 'true' replied:

> S: Well I saw the 3:1 ratio and thought yes.. that's for two heterozygotes.

These responses were typical of many students and indicate that the key information, and for some students, the single piece of relevant information used in 'solving' genetics problems of this type was the stated ratio. It was against this background that a further investigation was carried out of students' understanding of the concept of probability in the contexts of genetics and of "real life".

3. THE INVESTIGATION

The students who comprised this study group (N=59) had completed the first year of College level studies in general biology in 1982. This subject included a four-week study of basic genetics that comprised laboratory activities with Drosophila and placed a heavy emphasis on problem-solving tasks drawn largely from textbooks. In 1983 these students were enrolled in the second-year subject B08Genetics.

In the first weeks of study, the students completed as part of normal class activities two tests - a genetics test and a "real world" test. Each test included 6 items, and students were asked to answer each item and to give an explanation for their answers. The tests are detailed in Appendix 2.

4. RESULTS

The summary table below shows the result for each item on the two tests. The percentage of students giving a correct response for each item is shown in the table. For a student to be scored as correct for an item, both the correct answer was required and an explanation consistent with that answer.

	ITEM 1	2	3	4	5	6
GENETICS TEST	12%	12%	98%	16%	96%	30%
"REAL WORLD" TEST	86.4%	84.7%	96.6%	88.1%	96.6%	78%

For both tests, items 1, 2, 4 and 6 involved chance elements, while items 3 and 5 had a single outcome only. For the "real world" test, the mean score for the group for items 1, 2, 4 and 6 was $\overline{X} = 3.1$, s.d.= 1.3. For the corresponding items on the genetics test, the mean score was given by $\overline{X} = 0.7$, s.d.= 1.1. The sample size for the "real world" test was 59 students, and for the genetics test 50 students. The difference between sample sizes was due to absences from classes on the days on which the testing was carried out.

Students were not asked to identify their tests, but a few chose to do so. From this small sub-sample it was possible to compare the explanations given by the same student for his/her answers to the corresponding items on each test. Some examples follow:

Student#1:
ITEM 1A Male or female any combination - it is a random event
ITEM 1B 3 black and 1 brown $\quad$ Bb X Bb
$\downarrow$
1BB:2Bb:1bb

Student#2
ITEM 2A Any outcome. Insufficient data. Each toss is an independent event.
ITEM 2B 2 yellow and 2 green because green is dominant to yellow.

Student#3
ITEM 4A Probably coin A but could be coin B by chance.
ITEM 4B SS X ss ⟶ Ss
All offspring spotted ∴ genotype SS

These three students recognise the probabilistic nature of the outcome in the "real world" situations, but do not invoke the operation of chance in their answers to the items set in a genetics context. These students show a discordance in their operation in the two different contexts; they show an understanding of the independence of successive chance events and of the sensitivity of these chance events to sample size, but they use a different set of rules when operating in a genetics context.

Another type of student was identified among the sub-sample.

Student#4
ITEM 6A Green since there is a 1 in 4 chance of green to be on the bottom.
ITEM 6B Brown. Each parent carries an allele for brown. One offspring would be homozygous recessive.

Students of this type have a misconception of the operation of chance in both contexts, and appear to interpret a 1 in 4 probability of a given outcome as meaning that that outcome will occur once in each four events.

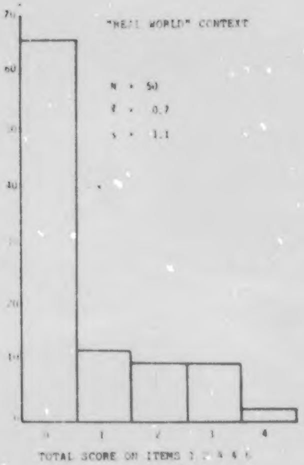
Other students displayed a clear understanding of the operation of chance in both the "real world" and in the genetics contexts.

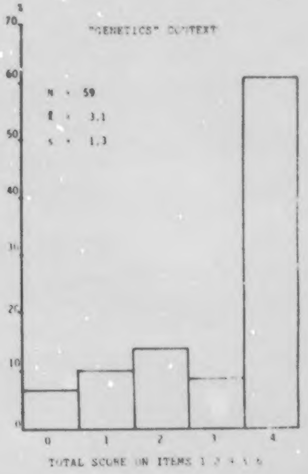
Student#5
ITEM 6A Yellow or green. As there is one side that is green the fourth toss can result in either green or yellow - depends on chance.
ITEM 6B Black or brown. Heterozygous matings have a 1 in 4 chance of producing brown but the fourth individual could be either black or brown.

The grouped results indicate that the majority of students showed a discordance in their responses in the two different contexts, and that they recognised the operation of chance more readily in the "real world" context than in the genetic context. It appears that the 'discordant' students have two working concepts of chance - one that applies in the context of Mendelian genetics and focusses on classic ratios applying them in a deterministic manner, and a second working concept that applies in non-genetic "real world" situations. The histogram below shows the distribution of total scores for items 1, 2, 4 and 6 for the two tests. It may be seen that the majority of students (61.1%) scored the maximum of four on these items in the "real world" context, but on the genetics items the majority of students(66%) scored zero.

The finding that most students showed a discordance suggests that these students are using a strategy which largely ignores the operation of chance when they are 'solving' genetics problems. This procedure would yield the "correct" answer in the genetics problem which is commonly couched in terms of

- What kinds of offspring and in what proportions would be expected from the following cross.... ?
- What percentage of the offspring would be expected to be.... ?





5. POSSIBLE SOURCES OF DISCORDANCE

Students of genetics develop their understanding of genetic ratios and their concept of probability as it applies in genetics from a variety of sources including participation in laboratory activities, problem-solving tasks and textbook readings. Most commonly, the breeding experiments which constitute the laboratory activies are chosen for their reliability in terms of producing the "desired" outcome, that is, they involve the use of organisms that produce large numbers of offspring fitting the expected result. Laboratory activities of this kind do not necessarily expose students to the probabilistic nature of genetic ratios and may not confront them with the critical influence of sample size.

Genetics problems are most commonly expressed in terms which fail to emphasise the probabilistic nature of genetic ratios. A study of 366 problems (Kinnear and Smith in preparation) dealing with mendelian genetics and selected from a range of textbooks revealed that 48% of these problems required as the student output the ratio or proportion of different kinds from a given mating - the "what-kind-of-offspring-and-in-what-proportion" style of question. Only a small proportion of questions used absolute numbers in the data provided, and very few problems dealt with small numbers of offspring.

Since performance on genetics problems is a measure commonly used to gauge student understanding of the concepts of genetics, it is suggested that the preponderance of the style of problem (What kinds and in what proportions....) may allow students to develop strategies that yield "correct" answers but do not also involve meaningful learning of the relevant concepts. A possible consequence of the bias in problem style is that students may tend to regard genetic ratios deterministic and to apply these ratios inappropriately to matings involving small numbers of offspring.

As part of their studies in the subject B08Genetics, students were exposed to problem-solving tasks using the computer simulation BIRDBREED (Kinnear 1982). These tasks were undertaken by students out of scheduled class times and they chould choose their own pattern and rate of proceeding through the assignment.

Unlike the problems found in textbooks which contain all and only the relevant data required for their solution, the computer-based problems comprised a statement of the problem only. The data necessary to solve the problem had to be decided on and generated by the student using the computer program and the student was required to judge the relevance and adequacy of the generated data. The program generates offspring from student-selected matings in small numbers, but allows students to accumulate larger samples by repeat matings.

Students were requested to complete an anonymous questionnaire on completion of the assignment. A sample of 44 students handed in a completed questionnaire.

The principal findings are summarised below :

More than three-quarters of the sample of students had had prior experience with a microcomputer.

Time spent working at the computer ranged from 2 to 13 hours; $\bar{X} = 4.0$, s.d.= 2.4

Time spent in follow-up work away from the computer ranged from 1 to 10 hours; $\bar{X} = 4.5$, s.d.= 2.5

Mean number of occasions on which work was done at computer was 3.5 sepatate visits with a std.dev. of 1.5.

Of the sample of students, 86% indicated that the use of the program helped their understanding of genetic principles, and 81.8% stated that the problem-solving tasks helped their understanding of experimental design.

The responses of student to the request to rate the computer assignment on a 0 (low) to 5 (high) scale in terms of several criteria are summarised below:

	MEAN	STD.DEV.
interest	4.3	0.83
challenge	3.6	0.96
enjoyment	4.1	0.81
level of difficulty	3.1	0.7
ease of use of program	4.4	0.95
value as learning experience	4.1	0.9
feeling of "being in charge"	3.9	1.03

The indication from these results is that the majority of students who completed the questionnaire rated the computer-based problem-solving tasks highly, and perceived them to be of value at a cognitive level and rated them positively on affective criteria.

When asked how the problems undertaken with the computer simulation compared with textbook problems, the student responses were:

Similar	29.5%
Different	61.4%

A small number of students (6.8%) indicated both similar and different, and 2.3% gave no reply.

When asked if the computer-based problems taught skills different from textbook problems, the student responses were:

Yes	75%
No	22.7%

2.3% of the sample gave no reply to this question.

Specific comments appended to the two questions above by students included:

> "We had to do our own work rather than stereotyped questions with perfect 'textbook' ratios. Two heterozygous parents did not give a perfect 1:2:1 ratio every batch"

> "It was different because you could see that the actual numbers and types of offspring are not always the same as Mendelian ratios predict"

> "It helped me to understand that even though there is an expected ratio of phenotypes that can occur, it is just by chance. Anyone of these phenotypes results"

> "It showed that the expected ratios need not result."

> "Textbook problems have only one set of data to consider.Here I had lots."

> "It taught me that the probability ratio does not always fit exactly."

> "These problems made me take into consideration what the genotypes of the birds may have been. You weren't given the exact information as in the textbook. It was was left to my judgment and discretion."

> "It just reinforced concepts I already understood from the textbook."

> "I actually had to think about the problem and not just follow a set pattern for working it out."

> "Here we were given a little information and mostly we had to do more thinking for ourselves, much better not to be spoonfed so much and then come to some conclusion on our own information and choose our own mode of attack."

These comments by students indicate a shift in their understanding to a more realistic view of genetic ratios in accord with their understanding of chance in "real world" situations. Some students however failed to reconcile their computer-based experiences with their prior understanding and were left with some sense of frustration expressed verbally to me as:

> "But I'm not getting a nice ratio!"
> "We should be getting fifty-fifty"

These students still tried to interpret classic genetic expectations as deterministic and did not show awareness of the critical influence of sample size.

Part of the final examination taken by students at the end of term included two items which tested understanding of the chance nature of genetic ratios and their sensitivity to sample size. The mean scores for these two items and for two comparable items which formed part of the early genetics test are given below:

	SCORE				
	0	1	2		
First test	78%	16%	6%	$\bar{X} = 0.3$	s.d.= 0.6
Final test	18%	23%	59%	$\bar{X} = 1.4$	s.d.= 0.8

These results also indicate a change in and refinement of understanding, but given the time interval between the tests, it is not possible to assign a single cause. The anecdotal evidence suggests the the extended range of learning experiences with the computer-based problem-solving tasks was a contributing factor.

6. CONCLUSIONS

The study indicates that students' understanding of chance as expressed in genetic ratios in some cases does not accord with their concept of probability as it applies in a "real world" situation. This lack of recognition of the probabilistic nature of genetic ratios and of their sensitivity to sample size may arise as a consequence of limitations in the learning experiences to which students of genetics are traditionally exposed.

The use of computer simulations which allow students to design and execute their own experiments as part of an 'active' problem-solving mode can broaden students' learning experiences and assist them to refine their understanding of genetic ratios. This applies in particular where the simulation allows for the accumulation of offspring on a small litter-by-litter basis.

The findings suggest that students should be explicitly exposed to the operation of chance in a genetic context, since transfer from the"real world" experience to the genetics context cannot be presumed to occur necessarily in all students.

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APPENDIX 1

"Real world" item:

Measured dosages of a drug are packaged into capsules in a pharmaceutical factory.
Each capsule is made of two halves that fit together.
Bin 1 contains 10000 havles, made up of equal numbers of red halves and white halves:

Bin 2 contains 10000 matching halves; 5000 of each colour:

A machine selects one half from bin 1, fills it with the drug and then seal it with a half from bin 2.
An inspector watched this process and saw four capsules made.
ANSWER THE FOLLOWING BY TICKING ( ) THE APPROPRIATE ANSWER(S)

The four capsules made could have been
4 all-white ( )
3 all-white and 1 red or bicoloured ( )
2 all-white and 2 red or bicoloured ( )
1 all-white and 3 red or bicoloured ( )
4 red or bicoloured ( )

"Genetics" item:

In horses black coat colour (B) is dominant to chestnut (b).
A black stallion was mated with two chestnut mares, and each mating produced a black foal.
Over subsequent years, these two foals were mated and a total of four offspring was produced.
ANSWER THE FOLLOWING BY TICKING ( ) THE APPROPRIATE ANSWER(S)

The four offspring could have been
4 chestnut ( )
3 chestnut and 1 black ( )
2 chestnut and 2 black ( )
1 chestnut and 3 black ( )
4 black ( )

APPENDIX 2

"REAL WORLD" TEST ITEMS

1A Mr and Mrs Taylor live in Carlton. Mr Taylor is an accountant and Mrs Taylor is a primary teacher. They have 4 children, aged 5, 8, 10, and 12.
What are the sexes of their 4 children?

2A Mrs Taylor went to the Wrest Point Casino and watched a game of two-up. She saw the toss of two coins. The result was H-T.
The process was repeated for a further four tosses.

The result of the 4 tosses?

3A Two coins are placed in a container -

Coin A is double headed;
Coin B has one face 'heads' and the other 'tails'.

One of the coins is selected at random.
It is tossed 4 times. The result is 2 heads and 2 tails.

Identity of coin?

4A Two coins A and B (as above) are placed in a container.

One of the coins is selected and tossed 4 times.
The result is 4 heads.

Identity of coin?

5A A tetrahedron has 4 red faces.

This tetrahedron is tossed and the color of the bottom face is recorded.

TOSS	COLOR OF BOTTOM FACE
1st	red
2nd	red
3rd	red
4th	?

6A A tetrahedron has 4 faces. It was painted so that 3 faces were yellow and one face was green. This tetrahedron was tossed and the color of the bottom face was recorded.

TOSS	COLOR OF BOTTOM FACE
1st	yellow
2nd	yellow
3rd	yellow
4th	?

GENETICS TEST ITEMS

1B Black (B) is dominant to brown (b). Two heterozygous black organisms were crossed and 4 offspring were produced.
What was the result in terms of color?

2B Yellow (y) is recessive to green (Y).
A yellow organism was crossed with a heterozygous green organism to produce 4 offspring.

The result in terms of colour?

3B Spotted (S) is dominant to striped (s).
A spotted organism (S-) is crossed with a striped beastie (ss) and 4 offspring are produced; 2 are spotted and 2 are striped.

Genotype of the spotted parent?

4B Another spotted beastie (S-) is crossed with a striped beastie (ss) and 4 offspring are produced, all of which are spotted.

Genotype of spotted parent?

5B Two homozygous recessive green organisms (gg) are crossed and 4 offspring are produced. The result is

OFFSPRING	COLOR
1st	green
2nd	green
3rd	green
4th	?

6B Black (B) is dominant to brown (b).
Two heterozygous black organisms (Bb) are crossed and 4 offspring are produced.
The result is as follows:

OFFSPRING	COLOR
1st	black
2nd	black
3rd	black
4th	?

"Do They Hear What I Say? - And Do They Understand What I Mean?"

Charles E. Lamb, University of Texas-Austin

Introduction

Communication in the mathematics classroom is of crucial importance. It is through communication that teachers and students interact as a part of the learning process. This communication of mathematics is primarily a linguistic endeavor (Lamb, 1980). Whether the communication be oral or written, it is of great importance that students and teachers receive information accurately. After the information is received, it must be interpreted correctly for application to the learning of mathematics.

For example, in a meaningful teacher-student dialogue, there are four things which must occur. They are: 1) the teacher says something; 2) the student hears it; 3) the teacher means something specific; and finally, 4) the student understands it. Clearly, this situation allows for several possible misconceptions to come about. When this happens, desired learning outcomes are often not achieved.

This paper will elaborate upon this topic by looking at background research literature, proposing a model of the process, citing classroom examples, suggesting remediation strategies, and providing recommendations for future research. A bibliography for further reading is provided at the conclusion of the article.

Background Literature

The ability to perform adequately in the area of language arts has been suggested as an important part of mathematical performance for several years (Lamberg & Lamb, 1980; Aiken, 1972; Skypeck, 1981). In general, research studies in the area have shown that the ability to operate in mathematical situations is closely related to language arts skills such as reading, writing, and verbal instruction (Gibb & Lamb, 1982).

For example, Beilin (1976) points out that the nature of the language used to express mathematical relationships may in fact, help to determine the structure of those mathematical ideas. Lamb (1980) confirmed this hypothesis in a study of selected measurement tasks dealing with number and length. In particular, when dealing with the measurement functions of length and number, students performing at higher levels on the tasks seemed most likely to describe relationships in terms of the range of the function.

The importance of language and its correct usage has been further underscored by many studies of a Piagetian nature. Many studies (such as Kidder & Lamb, 1981) have emphasized the importance of the questions used in clinical interviews. The studies point out the possibility of varied performance as tasks are manipulated relative to verbal questioning techniques.

As one considers the importance of appropriate language in the learning of mathematics, one needs to be concerned with the nature of mathematical language skills. For example, Lamb and Zehavi (1983) considered the important language arts skill of vocabulary as it is related to mathematics in the elementary school classroom. Their results indicate that many teachers experience difficulty with mathematical vocabulary. When this happens, it is likely that desirable learning outcomes are not achieved.

Misinterpretation and misuse of language is present at all levels of mathematics instruction. Wollman (1983) found that many college students had trouble when translating from a sentence to an equation. In elementary school, misconceptions may center about ideas such as zero. For example, "zero is not a number" and "zero is nothing" (Wheeler & Feghali, 1983).

The critical importance of language skill in the mathematical development of children has interested researchers and writers in cognitive development for some time. For example, Fuson, Richards, and Briars (1982) have elaborated upon the child's development of the number word sequence. In the same volume, Siegel (1982) points out that we must often separate a child's language from his/her mathematical knowledge of topics such as quantity.

Another source of confusion in the learning and teaching of mathematics is the use of symbolism. Skemp and others (1982) have studied this topic in some detail. They have considered aspects of symbolism ranging from the shape of the symbols, to mental imagery, to its effect on problem solving.

Related to the work on symbolic understanding, Skemp (1976; 1982) has dealt with the knowledge of mathematics by looking at levels of understanding and levels of structures. It seems that his constructs are useful to the present discussion. He distinguishes between two levels of understanding: instrumental and relational. Briefly, "instrumental" understanding is the possession of a rule and the ability to use it. At a more advanced level, "relational" understanding is knowing what to do and why. Related to understanding are the symbol-systems used to communicate mathematics. Here, a distinction is to be made between the surface structures (syntax) and deep structures (semantics). The surface structures are used to transmit the deep structures, which are at the very heart of mathematical meaning. That is, the deep structures make up the meaning of the mathematical ideas and their relationships.

Analysis and synthesis of the above, related literature heavily suggests that the communication of mathematical ideas is a very difficult yet important task. Skemp (1979, 1981) has looked at mathematics education in light of this dilemma and his results are mixed. On the one hand, he sees children as being challenged with a formidable, intellectual task, while being tied down by a system which hinders their progress. However, he hopes that by teachers untying themselves, they will then untie children and thus reap the rewards of children's amazing mathematical progress.

The Model

In this paper, linguistic interaction in the classroom has been discussed; both verbal and written. A potential process-model will be presented as a vehicle for studying this interaction. Hopefully, it is general enough to allow for consideration of both verbal and written communication.

Insert Figure I About Here

Obviously, there are several ways in which the system can experience malfunctions, (i.e. misconceptions can occur). The problem may be with the teacher, the student, or the interaction between them. For things to work well, a delicate balance must be achieved. This is often not the case in the mathematics classroom.

Common Misconceptions

The common misconceptions in mathematics are numerous and thus it is difficult to choose relevant examples for consideration. Misconceptions are abundant in areas such as number, operations, geometry, measurement, and problem solving.

Number

1) Children write "Ɛ" instead of "3".
2) Difficulty with 13 and 31.
3) Overgeneralizing from patterns.
4) Zero is not a number.
5) Zero is nothing.

Operations

1) "Communitative" property
2) Confusion among properties.
3) Translation from sentence to equation.
4) Division of fractions.

Geometry

1) Trisection of angles.
2) Vocabulary.
3) Perceptual problems.

Measurement

1) Units
2) Dimensionality

Problem Solving

1) Understanding the problem.
2) Related problems and details.

Remediating Common Misconceptions

While the remediation of particular misconceptions will require specific strategies peculiar to the situation, it should be possible, using the model and a carefully-detailed analysis to find the source of error and thus attack it. Some hypothetical situations are detailed below.

Number

"Zero is not a number" is a common misconception held by many students as well as by many teachers of mathematics. This misconception may have been brought about by related statements such as "zero is nothing", saying there are "none" in a set, or calling zero "oh" as if it were a letter. Providing useful descriptions for zero as a number should be helpful. That is, develop zero the same way as other numbers are presented.

Operations

Wollman (1983) reports that many college students translate "There are n times as many x as y" into y = nx. Principal sources of error were haste, failure to think of checking, failure to base the equation on meaning, and use of nonalgebraic symbols. Remediation was successful when checking and meaning were emphasized.

Geometry

Perceptual problems are common in the study of geometry. Perhaps certain concrete experiences will help with certain difficulties, while moving from the level of instrumental understanding to relational understanding may help to alleviate the problem of perception overriding logical thought.

Measurement

Students often have trouble with the relationships between the size of a unit and the number of units required to measure an object. For example, using a larger unit will result in a smaller number for the measurement. Physical understanding and experience will hopefully lead to the use of symbolism and relational understanding.

Problem Solving

Misconceptions or difficulties are apparent as students deal with problem solving in mathematics. Students who do not always perform well in problem solving, often spend much energy remembering specific problem details while ignoring (deep) structural similarities between related problems. It may be possible to emphasize this aspect of successful problem solving in a direct instructional manner.

Recommendations to Future Research

It appears clear that the quality of the interaction in the mathematics classroom is of crucial importance. It is hoped that the model presented here along with reflection upon it will stimulate continued research in the following areas.

1) Further conceptionalization and model building in order to further refine the process-model for classroom interaction.
2) In-depth, clinical investigations into classroom settings using the model.
3) Further detailing of common misconceptions in mathematics.
4) Research into remediation strategies for common misconceptions in mathematics.

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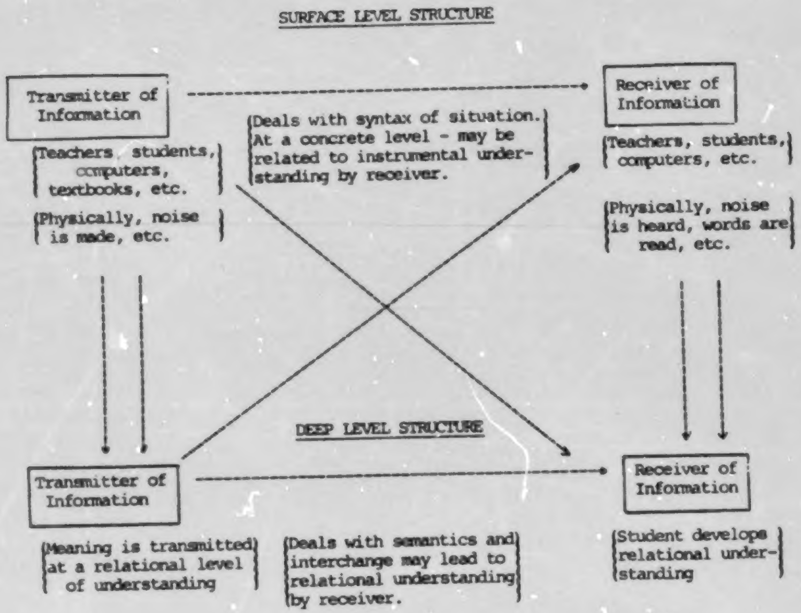
SURFACE LEVEL STRUCTURE
Transmitter of Information
Receiver of Information
Deals with syntax of situation. At a concrete level - may be related to instrumental understanding by receiver.
Teachers, students, computers, textbooks, etc.
Physically, noise is made, etc.
Teachers, students, computers, etc.
Physically, noise is heard, words are read, etc.
DEEP LEVEL STRUCTURE
Transmitter of Information
Receiver of Information
Meaning is transmitted at a relational level of understanding
Deals with semantics and interchange may lead to relational understanding by receiver.
Student develops relational understanding

Figure I: A Process-Model for Classroom Interaction
(Using Skemp's Notions of Structure and Understanding)

ALTERNATIVE MODEL FOR THE DEVELOPMENT OF FRAMEWORKS OF CONCEPTS AND IMPLICATIONS FOR INSTRUCTION IN SCIENCE

Gerald McClelland, University of Sheffield

I shall take it as established that, in the absence of instruction, peoples' ideas about physical phenomena differ from those of scientists, often to the point of incompatibility, and that students at all levels find it difficult to acquire and use scientists' concepts, as presented to them, except in limited and stereotyped situations. I shall suggest reasons why this should be so and make recommendations for practice.

Human thought gains its power, not by accumulating isolated pieces of information, but by merging information into concepts and concepts into elaborated frameworks. This enables the really values limited available processing capacity to be used to maximum advantage. Such a framework not only permits selective attention to the constant confused welter of sensory perception but also requires it. Part of selection is elemination. The value to the individual of such a framework resides in an enhanced capacity to respond appropriately, and without delay for reflection, to external circumstances. An appropriate response brings pleasure, which is a signal that the framework should be reinforced. An inappropriate response brings displeasure or pain, which is a signal either that the framework should be modified or that such situations should be avoided. These aspects of life which are most emotion laden and recurrent will call into play, and be reflected by, the most central, deep-seated and stable parts of the structure. Those which are low on these counts will be treated peripherally. Being right, wrong, or inconsistent will invoke an emotional response whose strength will vary in some direct way with the degree to which peripheral or central structures are involved. Where connections do not enhance appropriate action they will not be permanently established.

If this limited model has any validity, it becomes reasonable to ask what aspects of experience are likely to be most salient to an individual. For a young child, interactions with a mother, parents, siblings, other adults, and peers are recurrent and highly emotionally charged. It is in this area of experience that the child absolutely must learn to respond appropriately, so it is in this area that we can expect to find the earliest and most central framework of concepts. Language acquisition is an enormous intellectual feat. Yet it is accomplished by virtually every child. The high level of cognitive effort required is handsomely rewarded by enhanced ability to interact with others. Learning to live with others continues through adolescence and only ends if and when an individual has enough control over events to be able to eliminate from attention anything which conflicts with this central framework. It is no accident that most people spend their time with others much like themselves.

While interpersonal understandings are developing, each individual is embedded in a physical reality and experiences pushes, pulls, heat, cold, gravity, wind, water, and so on. As an individual it is necessary to know how to act appropriately and, for this, simple rules will suffice. As a member of a social group it is necessary to know the names for phenomena and the conventional phrases used for talking about them, as such talk is a vehicle for negotiation of relationships. Unless the rules or phrases lead to inappropriate action and evoke pain, there will be no reason to look for connections between the concepts nor to elaborate them into frameworks. Their degree of clarity and differentiation need not be expected to be greater than the accuracy with which their use has been experienced in context. The self-adjusting mechanism for selective attention should ensure that the time and effort, which would be needed, are not diverted from more salient areas. Conventional wisdom is conventional because it generally works. If a child were to develop different ideas and express them, social pressure might well lead to their suppression. This is not to say that a child cannot learn about physical phenomena in a consistent and interlocking way but that typical experiences and priorities are more likely to hinder than to promote such learning.

When an adult teacher or research worker decides to interview a child, it is usually in a school setting. Both through adulthood and through the connotations of the setting, the interviewer has a status which makes an attempt at a response virtually a social imperative. What the child says may not represent the results of reflection but instant inventions. It is not unusual for children to make confident assertions at first but, when asked questions, to admit to lack of understanding. Those who do not recant may be unwilling to make such an admission or may have crystallized new ideas from hitherto amorphous notions. Describing their assertions as beliefs or as representing frameworks of concepts seems to be to be highly dubious.

In general, scientists' concepts are encountered in schools, and it becomes the task of teachers to try to generate the extended attention and cognitive activity which is needed for meaningful learning. A setting in which herds of arbitrary size, based on chronological age rather than capability of interest, are taught by an individual is far from ideal. Added to this, most timetables promote the highly damaging implication that interest and excitement do not matter, for the interested child is denied the opportunity to pursue a task, and the disaffected is denied the opportunity to do something else. If, as I believe is often the case, what is presented is internally incoherent and not open to meaningful learning, it is hardly surprising that most pupils perceive their task as learning unrelated materials leading to standard tests beyond which all can be forgotten, and adopt a policy of 'strategic inattention' to topics not perceived as task-oriented.

If this argument is essentially correct, then the most fundamental requirement of science teaching is to persuade each student that the very real effort required to construct a new framework of concepts is worthwhile, and I believe this to be a very tall order. However, the following are recommendations which I see as consistent with such an aim:

1. Do not invite expression of ill-formed thoughts except perhaps in a very very released group atmosphere. Just as it is usually unwise to spell

out what is wrong to a class, it is unwise to bring to attention existing ideas when the new ones are not in a position to compete. It is time enough to attempt integrative reconciliation of ideas when there are ideas to be reconciled.

2. Present new ideas at high density with the fullest possible range of examples with the shortest time which can be managed. It does not matter that the ideas will not be understood clearly. You are demonstrating that they have wide currency and so are worth knowing.
3. Go through individual examples more slowly but always reiterate their relationships to each other. Do not let the trees obscure the forest.
3. Combine words and actions: do not expect meanings to be developed through words alone or actions alone.
4. Draw upon all possible 'real world' experience and examples: avoid the exclusive use of tailor-made apparatus and the implication that the ideas apply only to special circumstance.
5. Constantly signal simplications and idealizations: it is enough to point them out at the beginning and then to ignore them.
6. Do not allow questions and problems to become stereotyped.
7. Above all, do not teach something 'by the book' without understanding it: ensure that what pupils are expected to learn is, in fact, potentially meaningful.

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Can Metalearning and Metaknowledge Strategies To Help Students Learn How to Learn Serve as a Basis For Overcoming Misconceptions?

Joseph D. Novak, Cornell University

Introduction

For centuries, all serious teachers have recognized that students who learn rapidly and who can retain and use their knowledge in new contexts are not common. The question has been, why do some students learn so well and others so poorly? This challenge was met by Socrates with the strategy of "Socratic questioning" wherein through a clever sequence of carefully chosen questions, even the ignorant slave could be brought to understand the world as Socrates saw it. The assumption was that knowledge existed covertly in all of humans and proper questioning could reveal this knowledge in a way analogous to how the human potential was revealed when the homunculus in the sperm was freed to develop when it combined with the egg. No one believes today that the form of the human expands from the minature folded in the sperm and very few people believe that the knowledge exists performed in the human brain and the secret to intelligence is to find strategies to let it out. However, this paper will argue that there is great learning potential in humans that remains undeveloped in that many common educational practices impede rather than enhance expression of this potential. The thesis of this paper is that current knowledge about human learning (metalearning) and knowledge about the processes by which human's construct new knowledge (metaknowledge) can help to release much more of the intellectual potential of humans. Some recent research completed at Cornell University will be cited to support this thesis.

Psychological Basis for Metalearning and Metaknowledge

Since 1964, our research program has been based upon the cognitive learning theory of David Ausubel. His Psychology of Meaningful Verbal Learning (1963) and later Educational Psychology: A Cognitive View (1968) present a comprehensive, coherent theory of cognitive learning that is explicitly directed toward human learning, especially in school settings. Over a decade or so of application in research and instructional planning, we gradually came to understand his theory, and this work also led to some modification of the theory (Ausubel, Novak and Hanesian, 1978). Published in six languages, Ausubel's theory has had world-wide recognition, but probably least acceptance in the U.S.A. Nevertheless, our research group continues to find his theory, with a primary emphasis on the nature of meaningful learning, the most powerful and comprehensive for our work. We have added some aspects "cognitive science" to the theory and further modified the theory as regards cognitive dwvelopment (Novak, 1977a, b; 1980; 1982).

With regard to cognitive development our current view is that by age three, all normal children have essentially the same cognitive operational capacity as adults, but what varies from person to person and with increasing years are the frameworks of disciplinary specific concepts and propositions individuals possess. Our position is supported by recent work such as that of Kiel (1979) and Macnamara (1982), plus unbiased interpretation of almost all research dealing with human cognitive performance (see Novak, 1977b). However, I will argue in this paper that generically relevant cognitive learning strategies can be acquired and that it is possible that important qualitative differences develop in learners over the span of school years. In fact, we have suggested that these qualitative differences may account for much of the gross underpresentation of women in science and mathematics careers (Ridley and Novak, in press).

(Figure 1 About Here)

The key idea in Ausubel's theory is the nature of meaningful learning, as contrasted with rote learning. Ausubel's distinction here is at once simple, and also profound. He defines meaningful learning as non-arbitrary, non-verbatim, substantive incorporation of new knowledge into a person's cognitive structure, whereas rote learning is described as arbitrary, verbatim, non-substantive incorporation of new knowledge into cognitive structure, (see Figure 1). Taken by themselves, each of the words in the latter sentence is potentially obvious. We all know that verbatim learning occurs when we memorize definitions (e.g., a noun is the name of a person, place or thing) without stopping to consider the meaning of each word in the definition and their combined meaning. We all have experienced "losing points" on a teacher's test when our definition was not verbatim the teacher's definition. We may have provided a substantively identical definition, but we chose different words or word sequences to do it. We may have regarded the teacher's wording as arbitrary, but the teacher regarded it as a sacrosanct. In religious or mystical rituals, verbatim repetition may be sacrosant, but this should rarely be essential in school learning. Ausubel goes further to define meaningful learning as (a) requiring meaningful learning materials (Ebbinghaus did not do studies on retention following meaningful learning), a meaningful learning set, i.e., a disposition on the part of the learner to link each concept label in the new material with concepts he/she already possesses, and (c) relevant cognitive structure, i.e., some concepts* already present in cognitive structure that can be related non-arbitrarily to the new concept labels. As Macnamara (1982) has shown, young children do this remarkably well between the ages of 15 and 30 months. They also do something else that is remarkable -- all normal youngsters *discover* autonomously the meanings of some abstract concept labels such as *I* or *you*, or *she* and *me*. Subsequently they use these discovered concept labels to acquire from older children or adults the meanings of new concept labels, and "vocabulary" building accelerates rapidly until early school years. Macnamara found that his son, Kirnan, acquired meanings for 297 words (concept labels) in his 15th through 19th month but 211 words in his twentieth month.

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*We define concept as a perceived regularity in events or objects designated by a label. The remarkable capability "hard wired" into all normal human nervous systems is the facility to perceive regularities and to use language labels to encode these regularities. This is as much an evolutionary achievement of Homo sapiens as bipedalism. It does not have to be learned.

In case there are still any Skinnerians around, I would point out that to use 211 words without errors in simple two word sentences, Kirnan would have had to form $\frac{211!}{2\,!}$ S-R linkages during his twentieth month. Of course, not all two word sentences make sense, so we might divide this number by say a million -- a very generous assumption that only one in a million sentences with only two words Kirnan knows make English sense. I have not found a computer that will compute the number for 211 factorial, but it is essentially *infinity*. Even divided by 30 million, Kirnan would still have had to learn an infinite number of new English phases each day! So we return to the more plausible theory that the neurological hard wiring of humans permit them to acquire *meanings* for concepts and to relate these meanings in almost infinite varieties of ways. We do not yet know the neurobiology of this process, but then Mendal did not know that base pair sequences in DNA were determining the color, shape and size of his pea plants. We can apply valid psychological principles of learning without knowing the biochemical bases of these principles.

The principle of meaningful learning includes the idea that each of us has a unique sequence of learning experiences and hence each of us acquires idiosyncratic meanings for concepts. For this reason, Ausubel chose to use the word *subsumer* or subsuming concept to designate the functional unit in memory of each person. Each culture has more or less common meanings for the word labels for concepts, but each individual's subsumers are in at least small ways idiosyncratic. In some instances, this idiosycratic meaning departs widely from the culturally accepted meaning and we say the person has a *misconception* or *alternate framework*. Once established in cognitive structure these idiosyncratic subsumers are not easily modified, as is well documented by studies such as those presented at this seminar. Later we shall suggest some reasons for this.

Three other basic ideas form the core of Ausubelian learning theory which together serve to explain almost all cognitive phenomena. As new knowledge is acquired through meaningful learning, subsuming concepts undergo *progressive differentiation*, that is, new events or objects or concepts labeling regularities in new events or objects are seen as substantively related in the form of new *propositions** that include the original subsumer. Working from Ausubel's theory and current ideas from epistemology, we have developed a strategy we call "concept mapping" that can be used to illustrate progressive differentiation of concept meanings by the addition of new propositions (See Figure 2.)

(Figure 2 About Here)

Another key idea is that occasionally the meanings of two or more concepts will be seen related in a new significant way and *integrative reconciliation* takes place. For example, a student may learn that the concept of *space* is related to the structure of solids liquids and gases and then recognise that the amount of space between molecules accounts for the expansion of substances, and

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*Propositions are two or more concepts linked in a semantic unit, e.g. sky is blue; sky is air, sky is molecular. Propositions are the "molecules" from which meaning is built and concepts are the "atoms" of meaning, to use a rough metaphore.

not a "fattening" of the component molecules. Space and molecule take on new meaning. Whenever integrative reconciliation occurs, all of the concepts in the "reconciled" propositional framework take on at least slightly altered meaning. Occasionally, creative persons construct some novel integrative reconciliation (such as Eistein's $E = mc^2$) and our whole view of a segment of the world changes. I equate creativity with the ability and emotional proclivity to form "high order" integrative reconciliations. Rote learning not only fails to provide the basis for the latter but tends to inhibit search for integrative reconcilation -- as does much of school learning and evaluation. Human creative potential is probably at least an order of magnitude greater than what is now manifest as a result in part of the inhibiting effect of most school practices. Unfortunately, women are especially prone to be socialized into "playing the school game" and this may account in part for their underpresentation in the ranks of creative giants (Ridley and Novak, In press).

Occasionally a new concept meaning is acquired that subsequently serves to integrate the meaning of two or more concepts. Such *superordinate* learning is not common partly because disciplines do not have large numbers of truly superoridinate concepts and partly because subsumption appears to be an easier learning pathway. When superordinate learning does occur, one or several instances of integrative reconcilation may soon follow. For example, the chemistry students who acquires the meaning of entropy sees solubility, reaction rates and osmosis with substantively new meanings. To see what such superordination can do in a discipline, think what relativity has done for physics or plate tectonics for geology.

There is more to Ausubel's theory, and, of course, as a "living" theory it continues to be modified by new research. For example, our studies led to the necessity to include progressive differentiation and integrative reconciliation as key *learning* principles, whereas Ausubel's earlier work (1963; 1968) presented these ideas as principles of instructional design. A principle belonging to the latter category is Ausubel's *advance organizer*, but much writing erroneously almost equates this principle with his theory of cognitive learning.

Philosophical Basis for Metalearning and Metaknowledge

In my view, one of the tragedies influencing education has been the adherence of psychological and educational research to an outdated philosophical foundation. When Bacon proposed in 1620 advised that the scientists eshew preconceived notions and ideas and devote themselves to unbiased, objective observation, he was properly counseling against use of the mystical ideas that were held by many natural philosophers ("scientists") of his day. Bacon laid the foundations for *empiricism* or the notion that carefully observed and recorded reality can lead to *true* knowledge about how the world works. Psychologists, especially behaviorists, have rigidly adhered to this view for the past century. Most educational research that has grown out of this tradition also attempts rigid empiricism, albeit, this is much harder to do in classrooms than in the laboratory. Unfortunately, as Toulmin (1972) and more recently Popper (1982) have tried to point out, empiricism is dead, or it should be! We see a widely popular variant of empiricism in "cognitive science," but then most leaders in this dogma have their origins as behavioral psychologists. One does not easily change his/her epistemological stripes. This, I have argued (Novak, 1969; Novak, 1977a, Chapter 2), has been an albatross around the neck of those in educational inquiry and curriculum design.

It is not surprising that most textbooks, lectures, and examinations proceed as if ultimate truths have been found -- most teachers and researchers are still at least "closet" empiricists. In some of our recent research (Waterman, 1981; Posner and Strike, 1982) we are finding that empiricism is the widely prevailing epistemology. *Constructivist* views that knowledge is synthesized, modified and "evolutionary" in character are gaining ground and essentially all contemporary philsophers are some variety of constructivist (See Brown, 1979; Popper, 1982). Fortunatley, as I see it, constructivist views are also highly compatible with and complementary to an Ausubelian psychology of learning. Since the creation of new knowledge is a *learning* phenomenon on the part of the creator, we should expect congruence between a valid epistemology and a valid psychology of learning.

A decade and a half of attempting to help our colleagues in science departments to improve laboratory instruction gave rise to new educational research studies and methodologies for "unpacking" knowledge from original sources. Out of these efforts, Gowin (1981) came up with what we are finding to be a powerful heuristic for students and researchers, the Epistemological Vee. Figure 3 shows the general form and an example of Gowin's Vee applied to physics. Bacon may turn over in his grave to see that the Vee indicates *all* methodolgical elements on the "right side" are influenced by our concepts, principles, and theories and philosophies on the left side, but this is obviously the case in examination of any comprehensive report of an inquiry (Watson's (1968) book is a classic case here). It is also obvious that the "left side" controls the kinds of questions we choose to ask and the kind of objects or events we choose to observe; empiricism as noted early has locked psychologists into an "elegant" but largely fruitless enterprise by constraining the kinds of events observed and questions asked.

(Figure 3 About Here)

One may quarrel with the form of Gowin's Vee heuristic but to argue that it misrepresents contemporary epistemology is more difficult. We have seen no such arguments to date. Most of our students and scholarly colleagues in a wide variety of disciplines have reported profit and usefulness in applying the Vee to inquires in their disciplines. In any case, the Vee heuristic has appeared to have sufficient validity to use it as a device to help students learn about knowledge and knowledge production, and we have proceeded to use it to this end.

Empirical Studies

My thesis research (Novak, 1958) and our early research studies were based on a "cybernetic" model* for human learning derived from the work of Wiener (1948; 1954), Estes (1950) and others. The central focus in these studies was on the nature of problem solving and evaluation of instructional strategies to improve student's problem solving ability. By 1964, it had become increasingly evident that (a) our data were not consistent with predictions from a cybernetic learning model, and (b) acquisition of *specifically relevant* knowledge was the key factor in enchanced problem solving performance. These early studies are described elsewhere (Novak, 1977a, Chapters 4 and 8).

Fortunately, Ausubel's *Psychology of Meaningful Learning* became available just about the time our research group was ready to jettison cybernetic theory as a basis for our program. My conviction that any research program must have a theoretical foundation (acquired in part through my work in the sciences and history of science) was enhanced by Ausubel's work, since his theory of meaningful learning not only gave meaning to our earlier research data but also helped to combine my new interests in the central role that *concepts* play in science learning (Novak, 1964). This change in paradigm guiding our research led to many of the kinds of changes described by Kuhn (1962) including changes in the kinds of research questions we were asking.

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*Wiener's theory of cybernetics describes a model for information storage and processing that has led to modern automation devices and computers. Current "information processing" or "cognitive science" are based in part on cybernetic principles.

For the next decade, our research groups at Purdue University and since 1967 at Cornell University sought to apply Ausubellian learning principles in new instructional programs, including the development of audio-tutorial programs at the college, secondary, and elementary school levels (Postlethwait, Novak and Murray, 1964; 1972). The evaluation studies associated with these instructional programs provided strong support for meaningful learning theory (and considerable negative evidence for the highly popular Piagetian developmental theory). What remained a troublesome problem was the assessment of student's conceptual knowledge and changes in this knowledge as a result of new instruction. We found modified Piagetian clinical interviews (Pines, *et al.*, 1978) to be useful -- but also time consuming and impracticable for classroom teachers. Finally, with the work of Rowell in 1974-76, we developed an evaluation strategy we call *concept mapping*, and subsequently began to use this strategy not only to analyze interview data but also as a direct instructional technique with students.

Marco Moriera (1977) modified a syllabus for a college physics course on electricity and magnetism (E and M) to place central emphasis on the key concepts associated with Maxwell's equations. A control group used a more traditional syllabus (based on Halliday and Resnick, 1966) and the experimental group used the modified syllabus. Both groups were taught in a Keller Plan (1968) format and were instructed in making concept maps. Moriera found that the experimental group showed some decline in physics test scores early in the semester, but improved later in the semester (see Table 1). Using word association tests and concept maps for evaluation, Moriera found that the experimental group was better able to integrate key physics concepts in E and M and to show Maxwell's equations with proper concept map linkages. The results provided modest evidence for enhanced meaningful learning of E and M by the experimental students, but not at a level with substantial practical consequence.

(Table 1 About Here)

In a related study in college chemistry conducted in 1977, Cullen (1983) compared performance of students provided with a written study guide emphasizing the explanatory power of the concept entropy with students receiving more traditional study guide materials. Both experimental and control groups received the same lectures and did the same laboratory experiments. The lecturer discussed the entropy concept as it applied in various topics in chemistry. Using word association evaluation patterned after Preece (1976) Cullen found that the experimental groups included entropy more frequently as an associated word on students' word lists for the concepts: energy, atom, equilibrium, motion, reaction rate, solubility and temperture. He also asked students to generate statements using two concept words provided. Cullen constructed a "master list" of statements and found that most student responses could be matched with statements in this list. Experimental students used the entropy concept more frequently in their statements than control subjects (see Table 2).

(Table 2 About Here)

Another finding in Cullen's study was that students who used the entropy concept to explain novel problems in chemistry were not necessarily the "best" students as indicated by course grade (which was based largely on lecture examination grades). Some 85 percent of students receive grades of A, B, or C, but these students were almost randomly distributed when categorized according to the quality of their responses on novel problems (see Table 3). To the extent that Cullen's evaluation criteria permitted him to identify students with the best integrated conceptual framework for chemistry, course grades were essentially unrelated to such hierarchically organized knowledge. This finding is consistent with recent studies that show students in secondary or college science frequently have incomplete or erroneous knowledge of basic phenomena (Gunston and White, 1981).

(Table 3 About Here)

Both the Moriera and Cullen studies showed two phenomena that we now find rather consistently in our research. First, typical course evaluation methods do not require use of "high order," broad explanatory concepts and/or integrated frameworks of conceptual knowledge. (Note position of school learning in Figure 1.) As a consequence, when course examinations are the criterion of achievement, experimental approaches that emphasize use of broad explanatory concepts and integration of concept meanings will show little or no gains in performance. Second, the latter kind of experimental approaches frequently result in some initial decline on conventional course evaluation measures as students struggle to modify their learning patterns from more rote-mode to more meaningful-mode approaches. By the end of one semester, experimental subjects may equal or exceed their control conterparts, but achievement based on total test points scored may show no significant differences. This phenomenon is shown schematically in Figure 4. Unfortunately, we have not yet found an instructional setting in which our "experimental" approaches can be applied over several terms or years in sequentially related courses. Therefore, we can only speculate on the potential contribution of strategies to enhance meaningful learning as measured by either conventional course exams or more cognitively demanding evaluation techniques over the span of secondary and/or college instruction.

(Figure 4 About Here)

In another study relevant to the latter issue, Atkin (1977) found that strategies to enhance meaningful learning in a college organic chemistry course led to no significant differences on knowledge-type test items but a significant gain over control subjects on problem solving items ($x = 57.4$ vs $x = 37.7$; $p < .005$). However, on problems of a more sophisticated type, no significant differences were found except that students in both groups who were categorized on a pretest as "knowledge integrators" did much better than their "non-integrator" classmates ($x = 19.1$ vs $x = 1.8$; $p < .001$). It is to be expected that several weeks exposure to techniques to enhance meaningful (integrative) learning will not transform a student's total cognitive structure, a large part of which was acquired over a 20 year span of learning.

In 1974, I began using a draft of A Theory of Education as a textbook in my classes. My students, especially my undergraduate students, found that the book was interesting in terms of the issues discussed but what was of most value to them was that it helped them to "learn how to learn." After hearing this from students for several semesters, it gradually sunk into my head that explicit instruction in "learing to learn" would be a sensible thing do to. The studies by Moriera, Cullen and Atkin were efforts in this direction, but our first explicit efforts to use concept mapping as an instructional tool (rather than an evaluation device) was with college genetics students. We had been using concept mapping with graduate students and faculty in seminars on college teaching, so we knew this strategy was "teachable."

Bogden (1977) taught college genetics students the technique of concept mapping and then provided them with concept maps for each lecture given in the course. These maps were subsequently used by Bogden in his discussion sections. Figure 5 is an example of one of the maps prepared by Bogden. His study was not experimental but rather provided an assessment of the feasibility of using concept maps to help students' see conceptual relationships and relationships between specific genetic experiments and concepts illustrated or derived from these experiments. Bogden found a mixed reaction from the students, with approximately half of the students reporting some enthusiasm and perceived value in concept maps, and the other half being neutral or negative on their use. Some of the suggestions that grew out of his work were that concept maps should be kept simple (some maps were overwhelmingly "comprehensive"), lines connecting concepts should be labeled, and students benefit most from concept maps they construct. We also found that concept maps helped the professor to organize lectures, prepare exams and construct scoring keys. Some students were highly enthusiastic as regards the technique.

(Figure 5 About Here)

Partly from the work with Professor Brotman in the genetics course and Professor Holcomb in physics, my colleague Gowin invented a simple heuristic device to illustrate how scientists construct knowledge from the observation of events and object. He devised his Vee heuristic (Figure 3) in November, 1977 and we have been using it in essentially its original form since then. The Vee, when used in conjunction with concept mapping permitted us to offer both metalearning and metaknowledge strategies to our students. Again piloting the Vee heuristic in our seminars on college teaching, and informally with secondary and college students, we saw that this strategy was "teachable." College students frequently reported that they wished they were taught these ideas earlier, as in high school.

With funding from the National Science Foundation (our first federal grant for our research) we undertook a feasibility and evaluative study on the use of concept mapping and Vee mapping strategies with seventh and eight grade science students (age 13 to 15). After numerous problems with the development of appropriate instructional strategies and evaluation measures, we found that seventh graders could master these strategies at least as well as eight grade students over the span of a semester or two. No significant differences were found on conventional knowledge-type achievement tests for classes using or not using the strategies. There was both anecdotal and empirical evidence supporting the value of the strategies for problem solving, science reading comprehension and interest in science laboratory work (Novak and Staff, 1981; Novak, Gowin, and Johansen, in press).

Since 1980, virtually all our research studies have incorporate concept mapping and/or Vee mapping as strategies. Some of these studies have been directed primarily at questions of instructional design (Mollura, 1979; Buchweitz, 1981; Kinigstein, 1981) whereas others have been more directed at helping students "learn how to learn" (Melby-Robb, 1982; Gurley, 1982). Kahle and her colleagues at Purdue University are completing a related research study with predominately minority high school students.

The results from these and other studies show promise for the use of the strategies, but also serve to illustrate that it will not be easy to accomplish all of the educational changes that are needed. Whenever we use the strategies to assess curriculum we find serious conceptual gaps or lack of explicit linkages between concepts, poor integration between events or objects presented and concepts, principles and theories needed to interpret observations of the events or objects and little or no guidance to the student as to significant salient concepts vs peripheral or incidental concepts. Wherever the strategies are applied to student instruction, we find that students have a poor understanding of the nature of knowledge (see for example Waterman, 1982) and often little or no awareness of the difference between essentially rote as contrasted to meaningful learning strategies. It seems obvious that most students are unaware of the nature of their misconceptions nor how to "correct" them.

Summary and Recommendations

On the basis of our research and other recent relevant studies, we now see significant promise for concept mapping and Vee mapping strategies to help student "learn how to learn" and to acquire "knowledge about knowledge." We see these strategies as holding promise for helping students to understand both the nature and sources of valid as well as invalid conceptions of events or objects.

They may in time permit students to gain facility in assessing the power and validity of their idiosycratic conceptual frameworks. We believe computers can be helpful in this process and we are currently designing microcomputer programs to help students acquire and use concept mapping and Vee mapping strategies.

At this time, we have only a few strands of evidence, largely anecdotal, that suggest metalearning and metaknowledge will help students to recognise and "correct" some of their misconceptions. We have studies underway that should provide some hard data on this question. Our work is largely in the sciences, although one of our doctoral students, John Volmink, is getting some promising results with mathematics students.

But there is more that is needed. Schwab (1973) identified four" commonplaces "involved in education: teacher, student, curriculum and governance. There is still a need to help students learn how to be students and to help teachers learn how to be teachers. Concept mapping and Vee mapping can be helpful, but they are not sufficient for the latter tasks. They can also be helpful in curriculum improvement, as some of our research has shown. Gowin (1981) described governance as "the control of the *meaning* of experience" and while concept mapping and Vee mapping help to shift some of this control to the student, radical changes in school organization will be needed to achieve more liberating meaning in student learning experiences. We believe the theoretical foundations and the methodologies developed so far are "on the right track" and we urge and welcome their critical application by other educators.

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	N	Test One		N	Test Two		N	Test Three	
CRITERION:	Identification of General Concepts								
Experimental	37	1.11		35	2.11		35	2.46	
Control	35	1.23	-1.23*	34	1.53	4.41**	33	1.48	7.15**
CRITERION:	Idenficiation of Intermediate Concepts								
Experimental	37	1.03		35	1.60		35	1.89	
Control	35	1.06	- .63*	34	1.18	3.67**	33	1.30	4.18**
CRITERION:	Identification of Most Specific Concepts								
Experimental	37	1.11		35	1.83		35	1.97	
Control	35	1.20	- .95*	34	1.44	2.53**	33	1.52	2.81**

* P <.05   ** P <.01   (From Moreira, 1977)

TABLE 1: Average scores and t values for experimental and control groups on three concept mapping criteria at three intervals in the semester.

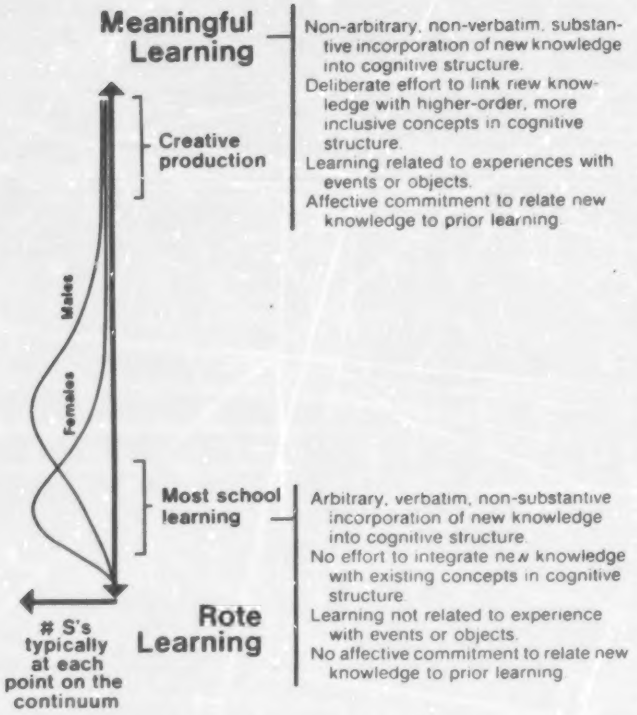
Relationship	Control	Experimental
Temp-solubility	2 (2)	8 (18)
Temp-rxn rate	1 (1)	1 (3)
Temp-equil	1 (1)	3 (8)
Rxn rate-equil	0	1 (1)
Equil-energy	0	3 (4)

TABLE 2: The entries in this table indicate the number of people in the study who used an entropy statement in the post-test to explain the relationship between two other concepts (TEMPERATURE and SOLUBILITY, TEMPERATURE AND REACTION RATE, etc.). The numbers in parentheses indicate the total number of statements that were made. (From Cullen, 1983)

	Response Category*					
	1	2	3	4	5	6
Question #3 (uncued)						
Control	/	C+, C	A, A-, B+, B+, C+, C-	B, C, C	/	/
Experimental	B, C+, C	/	C+	A-, A-, B-, B-, B-, B-, C-, C-	/	/
Question #4 (uncued)						
Control	A-, A-, B-	B+, B	A	/	A, B	A
Experimental	B-, B-, C	A-	A-	/	B-, B-, C	C

(The categories of answered are ranked from 1 to 5 are with 1 being no answer or irrelevant to 5 being an excellent answer.) (From Cullen, 1983).

TABLE 3: Final chemistry course letter grades for students who attempted to use an entropy argument in the uncued novel probelms.


Meaningful Learning
Creative production
Males
Females
Most school learning
Rote Learning
# S's typically at each point on the continuum

Non-arbitrary, non-verbatim, substantive incorporation of new knowledge into cognitive structure.

Deliberate effort to link new knowledge with higher-order, more inclusive concepts in cognitive structure.

Learning related to experiences with events or objects.

Affective commitment to relate new knowledge to prior learning.

Arbitrary, verbatim, non-substantive incorporation of new knowledge into cognitive structure.

No effort to integrate new knowledge with existing concepts in cognitive structure.

Learning not related to experience with events or objects.

No affective commitment to relate new knowledge to prior learning.

Figure 1: The rote-meaningful learning continuum as represented in Ausubel's assimilation theory of cognitive learning. Hypothetical curves show difference between male and female populations in mode of learning (with differences exaggerated).

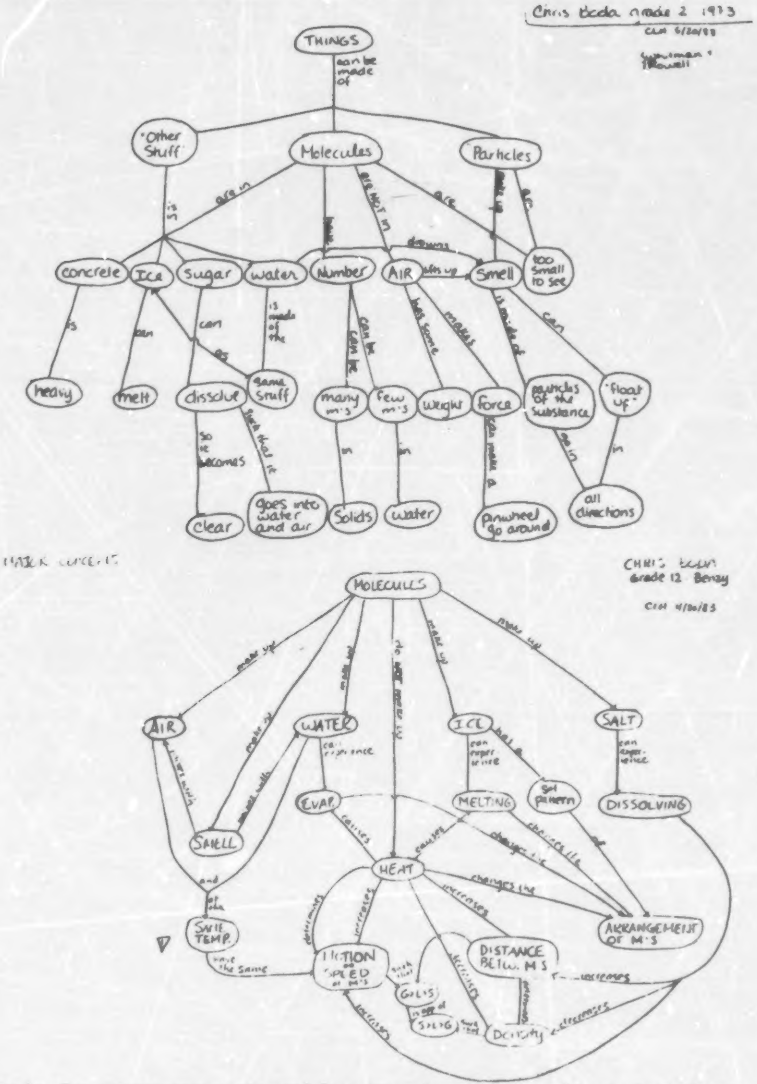
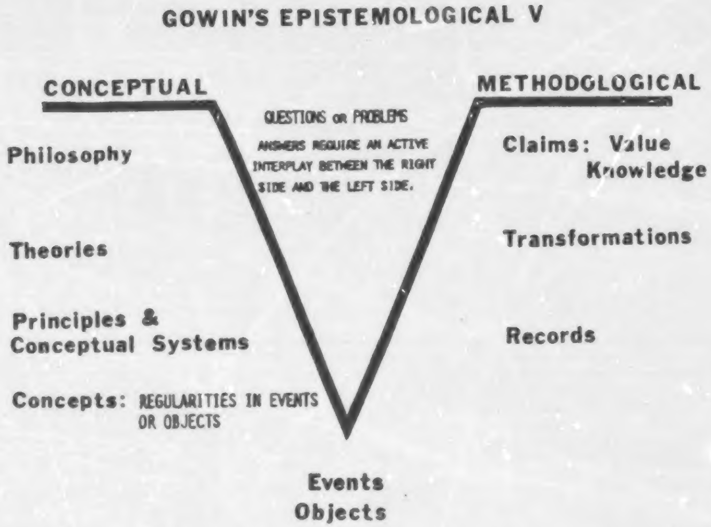

Chris Bodn grade 2 1973
CLM 6/20/83
THINGS
can be made of
"Other Stuff"
Molecules
Particles
is
are in
are NOT in
are
make up
are
drowns
concrete
Ice
Sugar
water
Number
AIR
lifts up
Smell
too small to see
is
can
can
as
is made of the
can be
can be
has some
makes
is made of
can
heavy
melt
dissolve
same stuff
many m's
few m's
weight
force
particles of the substance
"float up"
so it becomes
such that it
in
in
can make a
go in
in
clear
goes into water and air
Solids
water
pinwheel go around
all directions
MAJOR CONCEPTS
CHRIS BODN
Grade 12 Benay
CLM 4/20/83
MOLECULES
make up
make up
make up
make up
AIR
WATER
ICE
SALT
make up
can experience
can experience
has a
can experience
SMELL
EVAP.
MELTING
set pattern
DISSOLVING
and
causes
causes
changes the
changes the
of
SAME TEMP.
HEAT
changes the
increases
determines
increases
have the same
MOTION or SPEED of M'S
DISTANCE BETW. M'S
ARRANGEMENT OF M'S
such that
GAS
increases
SOLID
DENSITY
decreases
decreases
increases

Figure 2: Two concept maps contructed from interviews with a student in Grade 2 (top) and ten years later in Grade 12 (lower). Maps show "correction" of misconceptions and progressive differenation and integrative reconcilation of concepts dealing with the structure of matter.


GOWIN'S EPISTEMOLOGICAL V
CONCEPTUAL
METHODOLOGICAL
QUESTIONS OR PROBLEMS
ANSWERS REQUIRE AN ACTIVE INTERPLAY BETWEEN THE RIGHT SIDE AND THE LEFT SIDE.
Philosophy
Theories
Principles & Conceptual Systems
Concepts: REGULARITIES IN EVENTS OR OBJECTS
Claims: Value Knowledge
Transformations
Records
Events
Objects

CONCEPTUAL AND METHODOLOGICAL STRUCTURE OF LENSES EXPERIMENT AS VIEWED ON THE EPISTEMOLOGICAL VEE. (B. Buchweitz, 1981)

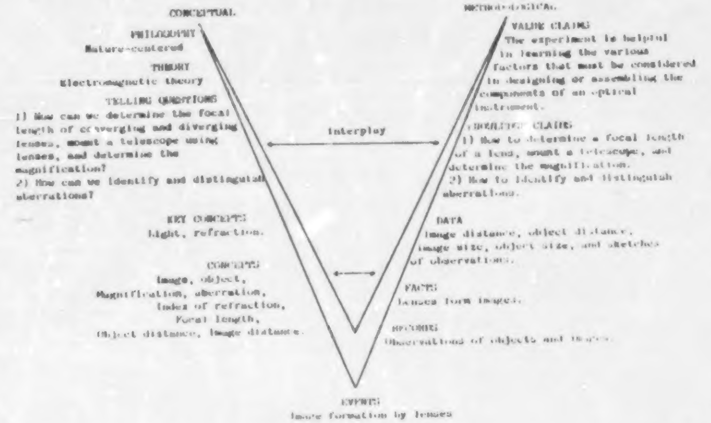

CONCEPTUAL
PHILOSOPHY
Nature-centered
THEORY
Electromagnetic theory
TELLING QUESTIONS
1) How can we determine the focal length of converging and diverging lenses, mount a telescope using lenses, and determine the magnification?
2) How can we identify and distinguish aberrations?
KEY CONCEPTS
Light, refraction.
CONCEPTS
Image, object, Magnification, aberration, Index of refraction, Focal length, Object distance, Image distance.
interplay
METHODOLOGICAL
VALUE CLAIMS
The experiment is helpful in learning the various factors that must be considered in designing or assembling the components of an optical instrument.
KNOWLEDGE CLAIMS
1) How to determine a focal length of a lens, mount a telescope, and determine the magnification.
2) How to identify and distinguish aberrations.
DATA
Image distance, object distance, image size, object size, and sketches of observations.
FACTS
Lenses form images.
RECORDS
Observations of objects and images.
EVENTS
Image formation by lenses

Figure 3: Gowin's Vee heuristic showing the ten basic elements involved in the construction of knowledge (top) and on example of the use of the Vee as applied in analysis of a physics experiment (lower).

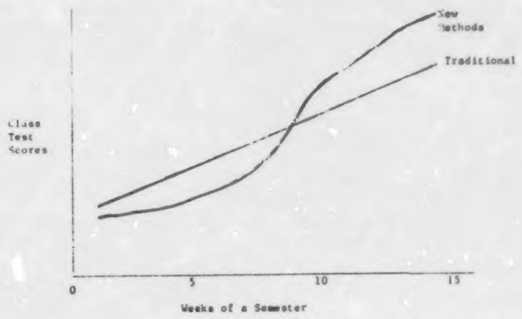


Figure 4: Hypothetic score curve obtained by students when new meaningful learning strategies are introduced as compared with more rote traditional approaches.

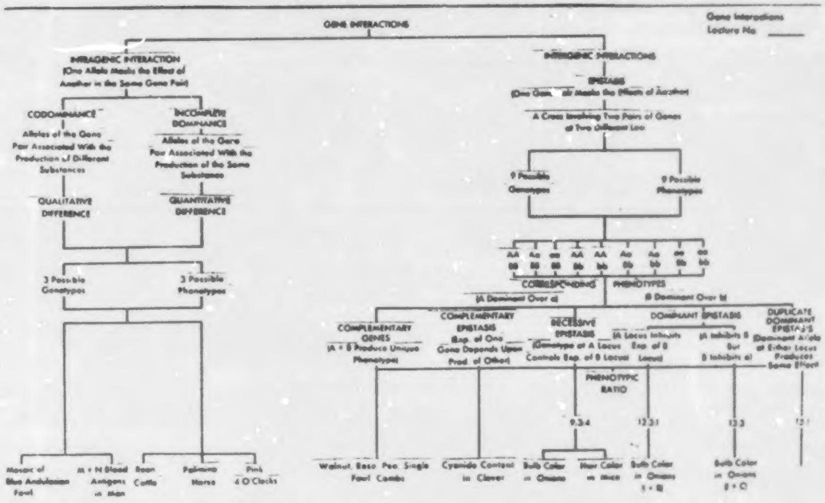

GENE INTERACTIONS
Gene Interactions
Lecture No. ____
INTRAGENIC INTERACTION (One Allele Masks the Effect of Another in the Same Gene Pair)
CODOMINANCE
Alleles of the Gene Pair Associated With the Production of Different Substances
QUALITATIVE DIFFERENCE
INCOMPLETE DOMINANCE
Alleles of the Gene Pair Associated With the Production of the Same Substance
QUANTITATIVE DIFFERENCE
3 Possible Genotypes
3 Possible Phenotypes
Mosaic of Blue Andalusian Fowl
M + N Blood Antigens in Man
Roan Cattle
Palomino Horse
Pink 4 O'Clocks
INTERGENIC INTERACTIONS
EPISTASIS
A Cross Involving Two Pairs of Genes at Two Different Loci
9 Possible Genotypes
9 Possible Phenotypes
AA BB
Aa BB
aa BB
AA Bb
AA bb
Aa Bb
Aa bb
aa Bb
aa bb
CORRESPONDING PHENOTYPES
(A Dominant Over a)
(B Dominant Over b)
COMPLEMENTARY GENES (A + B Produce Unique Phenotype)
COMPLEMENTARY EPISTASIS (Exp. of One Gene Depends Upon Prod. of Other)
RECESSIVE EPISTASIS (Genotype at A Locus Controls Exp. of B Locus)
DOMINANT EPISTASIS
(A Locus Inhibits Exp. of B Locus)
(A Inhibits B But B Inhibits a)
DUPLICATE DOMINANT EPISTASIS (Dominant Allele at Either Locus Produces Same Effect)
PHENOTYPIC RATIO
9:3:4
12:3:1
13:3
15:1
Walnut, Rose, Pea, Single Fowl Combs
Cyanide Content in Clover
Bulb Color in Onions
Hair Color in Mice
Bulb Color in Onions
Bulb Color in Onions

Figure 5: An early map prepared for one lecture in college genetics. Lines were not labeled, and specific objects or events (experiments) serving as illustration are included. (From Bogden, 1977.)

THE MICROCOMPUTER IN COGNITIVE DEVELOPMENT RESEARCH[1]
(or, Putting the Byte on Misconceptions)

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Cornell University

INTRODUCTION

This study represents a new application for laboratory simulation programs. The microcomputer's contributions to meaningful learning and cognitive development research are explored. This offers yet another potential for the microcomputer. A genetics problem-solving program, CATLAB, was used with 40 college students from an auto-tutorial biology course to generate unique data from real-world problems. The research addressed the learner's reasoning, problem-solving methods, and level of thinking concerning Mendelian genetics and meiosis. Missing concepts, conceptual weaknesses, and pre-conceived notions were identified. To see which of these conceptual problems persisted, were corrected, or were elaborated; paper and pencil tests, the microcomputer, interviews, and concept maps were used. The influence of these weaknesses on meaningful learning of genetics concepts was also considered. This paper is an interim report on the study currently being completed at Cornell University. It deals primarily with aspects related to the microcomputer.

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[1] This study is being completed in part with funding from the Division of Biological Sciences and The Graduate School of Cornell University. Additional funding has been made available through the Shell Companies Foundation.

BACKGROUND

The call for classroom related research into more effective ways of achieving meaningful learning is not new and is currently being sounded again on many fronts. The difficulty here is twofold. First, those involved in educational research are usually found in university settings. The descriptions and implications of their studies are reported in journals not usually read by or available to teachers. Second, precious few classroom teachers have time, resources, inclination, (or perhaps, expertise) to conduct research or to keep up on what is being done by others. It appears that one way to have relevant research conducted and the findings applied in the classroom is, as in this instance, to have it performed by teachers on leave from their teaching responsibilities.

I am troubled by the difficulties students experience in learning science concepts, in this case those relating to Mendelian genetics. It is my experience that many students learn the Punnett square as a device for solving genetics problems, but little understanding accompanies it's use. The student usually does not associate the process of meiosis with problem solving.

What DOES the student understand about Mendelian genetics? How DOES the student apply those concepts to solve genetics problems? Is there any evidence that the student regularly associates concepts from meiosis with his problem-solving approach? Does the student's "knowledge" of principles in Mendelian genetics simply involve rote learning of Mendel's laws, drawing of Punnett squares, and a fitting of all data to standard Mendelian ratios?

The above questions/problems may be solved to some extent by the teacher AND STUDENT each acknowledging his RESPONSIBILITIES. Additionally, I see the accessibility, versatility, and familiarity of the microcomputer as an opportunity for some meaningful research. It can serve to provide experiences with real data to bolster concepts already somewhat familiar to the student. It can also be used to test student's understandings of concepts. A properly designed computer program could require the learner to evaluate a situation, generate and analyze relevant data, and modify his hypotheses. He could then experiment further and draw a conclusion. This would be a fruitful tool for evaluating both teaching and learning: its potential should not go unexplored!

Some research dealing with student explanations and misconceptions in Mendelian genetics has previously been undertaken at Cornell (Bogden, 1977) and elsewhere (Stewart, 1982; Tolman, 1982). There previously has been no effort to correlate findings from the combination of methodologies used in this study with the Ausubel assimilation theory of learning.

This assimilation theory is concerned primarily with meaningful acquisition and long-term retention of concepts and how they are incorporated into cognitive structure. Past, as well as ongoing research, indicates it would seem useful in guiding modes of learning, teaching, and curriculum development.

The basic precepts of the theory include:

1. The inventory and developmental level of concepts already present in the mind of the learner are of utmost importance in determining the curriculum and instruction of subsequent concepts.

2. Subsuming concepts must be relevant to what is being learned if the learning is to be meaningful.

3. As meaningful learning (as opposed to rote mode learning) occurs, existing and new concepts are integrated and reconciled. New associations, nuances, and extensions of meaning are created and subsumed as part of the learner's cognitive framework. Concepts are progressively reorganized and recognized as being only part of a more inclusive picture.

A thorough discussion of this theory can be found in Ausubel, Novak, and Hanesian (1976). Its application as a theory for education is presented by Novak (1977).

This study reflected this theoretical base. It was designed to assess the extent to which concepts had been meaningfully learned, what refinement and application of those concepts occurred, and how well the student interrelated the entire conceptual picture of the topic. The data reported here are taken primarily from that phase of the study which used the microcomputer.

THE STUDY

A stratified random sample of 40 students from an auto-tutorial introductory biology course participated in the study. A mean time of 3.5 years had elapsed since any of them had had any Mendelian genetics. The students were first asked to complete a questionnaire about their past and present educational experiences. Some relevant affective questions were also included. A genetics assessment test (GAT-1), based on principles of meiosis and Mendelian genetics taught primarily in high school, was then administered.

Each student then participated in an interview during which he was given the opportunity to describe his understandings of genetic terms and to demonstrate the process of meiosis using chromosome models. Questions and difficulties from his test paper were also discussed. Where possible, the interviewer constructed a derived concept map of the student's understanding of meiosis and Mendelian genetics from this interview.

The next phase divided the sample population into two groups. One group worked primarily with microcomputer problems and the other with conventional problems. The two sets of unique problems were as parallel in type and difficulty level as possible. Sample parallel problems can be found in Figure 1. Problems in both sets fell into the following categories.

1. determining genotypes from phenotypes using one trait crosses,
2. incomplete dominance,
3. predicting phenotypes and genotypes using two trait crosses,
4. sex linkage,
5. autosomal linkage and crossing over, and
6. gamete production and composition.

The non-microcomputer problems were taken verbatim from the text for Introductory Biology 106, (Keeton, 1980). The computer problems were selected or written from the CATLAB program (Kinnear, 1982).

CATLAB is not merely a drill and practice program. Neither, does it prompt the learner simply to answer pre-established questions to generate data which is then plotted to show a particular relationship. It requires the student to UNDERSTAND the underlying genetic principles. He must plan and execute original experiments which generate data needed to solve problems involving coat color and pattern in cats. So, not only must the learner understand the salient concepts in genetics, he must also use skills of science research methodology.

CATLAB is an appropriate program to use in a study based on the Ausubel cognitive learning theory. This theory views concept development as progressing from the most general, inclusive concepts to the most specific, least inclusive. Likewise, concept mapping arranges concepts hierarchically from most general at the top to most specific at the bottom. CATLAB forces the student to work with and consider the more general level of a concept (phenotypes) and to proceed by deduction to the more specific (genotypes). For a discussion of some affective and cognitive gains from using CATLAB in a college genetics course, see Kinnear, Martin, and Novak, in press.

Both sets of students were scheduled for six hours of problem-solving time over a three week period. During that time problems from each set were tried by students from each group. Each student worked as many problems as seemed practical for his level of understanding, but was not necessarily expected to solve every problem. Interviews were conducted during the problem solving sessions. The interviewer provided appropriate data as needed for students completing microcomputer problems on paper. It should be noted that all students were concurrently completing regular course requirements for Unit I (meiosis) and Unit II (Mendelian genetics) at the time they participated in the research.

Next, all students were taught the principles of concept mapping (Stewart, VanKirk, and Rowell 1979). Each was then asked to construct a map from a prepared list of genetics concepts. Individual interviews were conducted to discuss the maps and to provide the opportunity for the student to make any additions or corrections. He was also asked to again demonstrate the process of meiosis and to answer specific content and affective questions.

To complete the study, the same genetics test administered earlier was given again (GAT-2) and the genetics questions missed on the final examination for the course were inventoried.

PRE-INSTRUCTIONAL CONCEPTUAL DIFFICULTIES

Selected excerpts from case studies will be presented to acquaint the reader with typical pre-instructional student errors and misunderstandings. For the purposes of this paper, the focus will be on three specific areas: vocabulary knowledge, understanding of meiosis and how it relates to problem solving, and the Punnett square method of problem solving. Theoretical interpretations of the occurrence of these areas and their educational implications will be considered.

Data collected to assess the extent of initial knowledge substantiated my belief that, although most of the concepts would be familiar to the students, they would have forgotten much since their high school days.

In checking vocabulary knowledge, varying abilities of recall were seen. Some terms were correctly remembered by better than 80% of the students, while other terms were familiar, but could not be defined. Phenotype and zygote were known by most students, while allele was known by very few. None could correctly define crossing over. Thirty-three of 40 students could not distinguish between meiosis I and meiosis II. See Table 1 for specifi-

vocabulary data.

Understanding meiosis and how it is used in problem solving was also investigated. Student B19 expressed a common sentiment that even if meiosis and Mendelian genetics were organized sequentially in the text, there may have been no effort to relate the two.

> I: "Do you normally associate having to know meiosis with being able to do Mendelian genetics?"
>
> B19: "I think maybe because of the high school course, well, most high school courses, they were only put under the same topic, but they were never really related."

As a consequence of statements similar to the above, it is little wonder that 17 of the 40 students saw no connection between meiosis and genetics problem solving. The remaining 23 students knew there was a relationship, but only 3 of those could remember the details of meiosis. These three had learned meiosis, knew there was a connection to problem solving, but could not specify that connection. This created a variety of difficulties, most of which stemmed from inability to correctly determine the gametes produced. Consider the following transcript excerpt taken from the pre-instructional interview.

> I: "Do you see any connection between the topics of Mendelian genetics and meiosis?"
>
> A13: "No, I just had them together when I studied it."
>
> I: "But you don't know why?"
>
> A13: "Right."
>
> I: "Let's look at question 5 (from GAT-1). How did you determine the answer?"
>
> Question #5: In guinea pigs, black coat color is due to a dominant gene (B) and white coat is due to its recessive allele (b). What are the possible gamete types, with respect to coat color, produced by a guinea pig heterozygous for coat color?

(A) BB, bb *(B) B, b +(C) Bb, bb (D) b, b

*denotes right answer
+denotes student A13's answer: 17 of 40 students missed this problem, with 15 of them selecting answer C.

> A13: ".....I thought you put both. If it was heterozygous you put 1 for the dominant and 1 for the recessive and crossed those instead of...I guess because I thought a gamete had 2 instead of just 1."
>
> I: "OK. So you thought you were putting both of the genes in the gamete."
>
> A13: "Um-hm... instead of just 1."

This student learned how to use meiosis as she worked through Units I and II and did not miss meiosis questions on the final examination. However, her concept map at the conclusion of the study showed only some concession to the importance of meiosis. (Correlation with concept maps is beyond the scope of this paper. However, two examples will be included later.) It seems, from these observations, that the student had memorized the outcome of meiosis and how to use it in a limited sense, but had not linked the relevant concepts in a meaningful way.

The following is another example of the same type of problem.

> I: "Do you take into account the process of meiosis in any way when you use the Punnett squares?"
>
> B11: "It helps you understand why you're using the squares, but you don't need to know anything about meiosis. I mean you could do the problems, if you're taught to use the squares, without knowing anything about meiosis."
>
> I: "Was there any part of that process of using the squares that you think was made easier by your knowing meiosis?" (B11 had previously correctly demonstrated meiosis using the models.)
>
> B11: "Oh, yeah. It would."
>
> I: "For example?"
>
> B11: "Knowing that meiosis is the process that gives you the gametes with 1 gene, with 1 trait on it."

Student B11, even though admitting the importance of meiosis, had missed questions 6 and 7 involving two traits and question 14 about sex linkage on the GAT-1. She also missed the linkage and two trait questions on the course final.

Some students realized that meiosis COULD be used to do the problems, although they did not feel it essential. It was also obvious from some interviews, that the significance of integrating the two ideas had not been grasped. The comments of student A4 are appropriate here.

> I: "Could you show me how these (chromosomes) go through meiosis?"
>
> A4: "If I can. I don't think I can do it. Boy, this is embarassing. I don't remember the process. I remember it somehow. This gets split and 1 copy to each thing."
>
> I: "OK."
>
> A4: "One thing I remember, there are 4 - I'm not sure what they're called - I remember there is a name for them. I don't know if they're gametes or there's an intermediate step. There are 4 cells produced, then. I have some impression that some are discarded in some way, or maybe not. But, that could be something else. This is a long time ago, I really don't know what I'm talking about."
>
> I: "Well, when you do a genetics problem using the Punnett squares, do you use them because you feel that that's a good way to do the problem and not have to worry about the meiosis?"
>
> A4: "Well, I use that because if I tried doing it with meiosis I probably wouldn't remember enough of it. And, that's the way it was taught."
>
> I: "You don't feel you need to know all this business about meiosis to use the squares?"
>
> A4: "No you don't. That's a problem with the way the Regents is set up. You can get through without understanding anything."

This student continued to miss gamete formation and meiosis problems on the second administration of the Genetics Assessment Test. She also missed the meiosis question on the course final. Her concept map did show some correct propositional links with meiosis.

The Punnett square was the most common problem-solving method used.

However, students had difficulty in explaining how it worked or interpreting the results. This was most obvious when students were asked to solve two trait problems or answer specific questions using the squares. A wide variety of difficulties and explanations were demonstrated. Two examples given here are illustrative of the types of pre-instructional problems experienced by the students. GAT Question #6 was used as one focal point in the interviews.

Question #6: In cocker spaniels, the gene for black coat (B) is dominant over its recessive allele for red coat (b). Solid coat (S) is dominant over spotted coat (s). A dog heterozygous for both traits is mated to a dog homozygous for both solid and red. This mating would be solved as follows:

```
(A)____¦Sb¦Sb   +(B)____¦SS¦bb   *(C)____¦Sb¦Sb   (D)____¦Sb¦Sb
    Ss ¦  ¦          Sb ¦  ¦          SB ¦  ¦          SB ¦  ¦
    Bb ¦  ¦          SB ¦  ¦          Sb ¦  ¦          sb ¦  ¦
                     sB ¦  ¦          sB ¦  ¦
                     sb ¦  ¦          sb ¦  ¦
```

*denotes the correct answer
+denotes the answer for students A7 and A17: 31 students missed this question, 20 selecting answer B. One of the 20 chose both B and D.

I: "What was the difficulty you had with question 6."

[illegible]: "[illegible] expecting it to be a square."

I: "Do you mean having just 4 answer spots?"

A7: "Four spots or 16. I didn't expect to have 6 or 8."

I: "So, the problem with question 6 was that the Punnett square didn't seem to have the right number of squares in it?"

A7: "Right, it wasn't a square."

Further discussion with student A7 revealed he worked the problem without meiosis and DID determine the four correct offspring possibilities. He did not pick answer A because he "knew there should not be 3 of the same letter in an offspring." Answer D was not selected because it did not provide all 4 of the offspring possibilities. He stated he did not select answer C because it showed 8 offspring. Answer B was finally selected because the letters across the top represented the genotype of one of the dogs, SSbb.

Student A7 continued to miss meiosis and two trait problems on the GAT-2 and the course final. His concept map clearly indicated that he had not grasped the significant role of meiosis and did not meaningfully link it to other relevant concepts. The map showed only one trivial link to meiosis (Figure 2).

In addition to the arrangement of squares, the determination of the proper gametes complicated this problem for some. It was not uncommon for students to state that the letters on the outside of the square represented the parents in some way (other than as gametes).

A17: (Discussing problem 6) "Well, I worked this one out because I figured this would be heterozygous 'cause it was different and this 1 would be homozygous. So, that was the only 1 that was heterozygous way, so that was why."

I: "So in 6, you picked B because across the top it was homozygous?"

A17: "Um-hm. That's the only one I know.

I: "Do you see any difference between answer B and answer C?"

A17: "Um....yeah. 'Cause I thought that was homozygous 'cause it had 2 SS's and these don't, they're both heterozygous. I know these are heterozygous."

I: "You're thinking that those letters across the top are representing the parents, as you told me before?"

A17: "Um-hm."

Student A17 did not relate the ideas of independent assortment or segregation to her use of the Punnett square. But then, her misconception that the letters above the squares represented the parents did not require knowledge of those other concepts. There would be no need for this student to associate meiosis with general problem solving. The student's interpretation of what the letters represented did not pose a difficulty in a one trait problem; she, along with several others, just divided the two letters for the trait, placing them in the spaces at the top and left of the Punnett square. They then combined the products into the inner boxes. Of course, this misconception led to difficulties in a two trait cross. Although student A17 missed no further questions on gamete formation, she still continued to miss the more specific meiosis questions on the GAT-2 and the course final.

Several students perceived no reason to consider meiosis unless it involved linkage or crossing over. In these latter cases, they realized the need to consider the role of the chromosomes.

Ausubel (1978) has stated the importance of determining what the learner knows prior to instruction. This study was begun with that thought in mind. It has been shown that the GAT-1 and pre-instructional interviews identified some trouble areas. It was believed they would serve as advance organizers for directing the student's attention to specific weaknesses on which he could concentrate and seek clarification during subsequent study. Consequently, it was expected there would be some perfect scores two months later on the second administration of the GAT. These assumptions were not substantiated.

RESULTS WITH THE MICROCOMPUTER

The CATLAB microcomputer laboratory simulation program provided an excellent opportunity to involve the student in his learning and to challenge his existing notions about how principles of genetics operate. It immediately made him aware that genetic combinations in actual cat populations differed widely from those derived from completed Punnett squares. The program also forced students to consider the more general level of a concept (phenotypes) and to proceed to the more specific (genotypes). The principles of concept mapping and Ausubel's learning theory are both supported by this line of thinking.

The purposes of this part of the study were to observe and to listen to the student as he went about solving genetics problems on the microcomputer. The intent was to see if the microcomputer: (1) provided any insight for the investigator or learner into the reasons for the difficulties seen thus far, (2) revealed conceptual strengths and weakness which could be correlated with other evaluation measures, and (3) contributed to meaningful learning.

One immediately obvious misconception shown by many students refers to the number of offspring expected from a cross. All but one student were familiar with a 2x2 Punnett square to produce four offspring. Many had also seen diagrams of meiosis showing four cells, not necessarily labeled as gametes, being produced from each primary sex cell, e.g. Kraus, 1983, p. 298. I feel that these two conditions have contributed to students' misapplication of the use of the Punnett square.

The transcript excerpt which follows is taken from an interview concerning the problem below. This problem was missed by 11 of the 19 microcomputer students who tried it.

Problem 1C: Using CATLAB, mate a black cat with a grey cat. Record your results. Determine whether the offspring are homozygous or heterozygous. What is the genotype of the black parent? Use CATLAB to prove or disprove your answers. Which is the dominant color, black or grey? How do you know?

> If 2 black F1 were mated, what F2 ratio would you
> expect? Did you get that ratio? If not, why not?

The first student quoted had been working on this problem and was discussing a cross between two F1 black cats.

I: "What if the black had been heterozygous?"

B1: "Ok, if the black cat was heterozygous and black was the dominant color and grey was homozygous, then I would have expected at least 50% grey, homozygous."

I: "Do you think with a litter size of four, that that's a sufficient number to rule out the possibility........"

B1: "Probably not. That's just the number I'm used to working with."

I: "Why do you settle on four? Why does four seem a comfortable number for you to go with?"

B1: "Because it's the number I usually pick in my crossings, in the Punnett squares, and it's easier to count. If I get an odd number I might not be able to make it....work in..... the Punnett square."

The following student was troubled throughout her work that she was not getting results which matched her Punnett square. She believed the cats must perform just as shown in a Punnett square. Anytime a litter was generated which did match, she drew her conclusion. As a result, she routinely made decisions based on limited data and, typical of many students' interpretations in this problem, did not consider equally correct alternative explanations for her data. She worked on this problem for an hour, but never realized when she had conclusively determined the dominant color.

I: "Program the cats in and do the mating and then we'll go from there."

A18: "OK, I crossed the black female and the grey male and I got 4 black females and 1 black male. Now I don't know how to do a Punnett square that would work out where I would have 5. If this were homozygous........

I: "The female is homozygous black?

A18: "Yes. Right."

I: "You're writing black as dominant?"

A18: "Um-hum. Because they all turned out to be black."

I: (later) "Alright, let's go back to a statement that you made earlier. And that was that you didn't know how to work the Punnett square when there were 5 offspring. What's the problem, where are you confused?"

A18: "Does it have something to do with male and female?"

I: "I don't know, that's what I'm asking you. Where are you confused with the Punnett square?"

A18: "Because when I do this (working out a Punnett square on paper), I only get 4 offspring."

I: "When you put 2 little b's across the top and 2 big B's down the side, you only get 4 offspring."

A18: "Um-hum."

Student A18 also continued to misinterpret results in quertions on the GAT-2. Her concept map lacked several significant links involving alleles, meiosis, crossovers, and linkage.

Another common misconception is also evident in the above transcript. The phenotype that was PREDOMINANT in the first litter was assumed to be dominant. In many instances, jumping to this conclusion gave the student a great deal of difficulty in trying to solve the problem. Notice that student A18, because she had received 5 black cats in the first litter, assumed black was dominant. These 5 black cats would also have been possible if grey were dominant.

The Punnett square acted as a very influential anchoring concept. The student tied several seemingly related concepts to it without considering the limitations or implications. It was clear that she did not relate genetics, meiosis, and probability.

Many students felt that data should always fit the various ratios they had memorized. It was their common experience that Punnett squares faithfully generated those perfect ratios! Variations on these numbers had never been considered. When they were encountered, the students were not sure whether to accept them or how to deal with them.

An interview excerpt relating to Problem 2 is a case in point. Of the 20 microcomputer students, 13 could not do this problem without a great deal of prompting.

> Problem 2C: A litter resulting from the mating of two cats, both of which have only some white in their coats, produces 2 kittens with no white, 1 kitten with extensive white, and 5 kittens with only some white. Using CATLAB, what would be the simplest way of explaining the inheritance of regions of white on the cat's coat? Also, from the CATLAB program, determine the parent gerotypes.

I: "Well, what do you think about these results you are getting?"

A11: "Don't ask me now. I just got something I totally didn't expect."

I: "What?"

A11: "I was going on the...this grey cat just sort of....hopped in. Which I haven't seen yet."

I: "You were assuming that that was not a possibility?"

A11: "Well....no....I guess not....I don't know....I've got to think about this some more."

I: (later) "What was throwing you off in this that you kept looking at the data and making another cross?"

A11: "It's because I kept getting such strange results. Like this didn't come out 1:2:1 at all. It didn't even come close." (The student was basing these comments on 36 offspring.)

Similar concerns were expressed in the interview with student A5. An excerpt is given below.

I: "OK, you're looking at the data in the problem."

A5: "Yeah, and I'm wondering if the parents could be heterozygous, but the ratio for kittens isn't right."

I: "What do you think it should be?"

A5: "Well, if the parents are heterozygous I would think it would be 1:2:1. Or the phenotypes actually would be 3:1. Am I doing this right?"

I: "What ratio do you have there?"

A5: "The ratio I have here is 2:5:1."

I: "But you don't think that fits this problem?"

A5: "No, simply because the numbers are so far off. It just doesn't seem to fit quite right."

Student A5 did not realize how unusual her data really were. Not only had she gotten a very close ratio, but it had been generated with only 8 offspring! This student had difficulty interpreting results in other problems. In 5AC, she picked the appropriate cross to use, but had trouble explaining expected results with and without linkage. Once she started getting data, she could not interpret how it contributed to the solution of the problem. Finally, she abandoned any explanations and drew her conclusion (a wrong one) based on what she THOUGHT might be true from looking at the kittens produced.

Student A5 also continued to miss test questions which required interpretation of results. On the CAT-2 she missed the questions on Mendel's laws, 2 traits using Punnett squares, and linkage and crossing over. On the course final she missed 2 interpretive problems dealing with chi square and blood types.

The source of student A5's confusion is difficult to specify from her concept map. Some significant linkages are missing from her map and may contribute to her difficulty. For example, she did not make links between phenotype and genotype, chromosomes and linkage, or alleles and meiosis. The student said during the interview that she had much difficulty with linking words for the map and she felt many connections were too trivial to place on the map.

The microcomputer and particular laboratory simulation program used in this study played a significant role in identifying the types of procedural errors described thus far. These were not isolated instances which have been cited, but represented common threads of difficulty seen at one time or another in several of the students.

The misconceptions presented here are indicative of conceptual weaknesses. Interpreting these errors in terms of Ausubel's theory of meaningful learning should wave a flag at the teacher signaling areas for remediation and suggesting specific courses of action. In this case, either the needed concepts have not been subsumed, or linkages among appropriate relevant concepts have not been made, or both.

Attempts to solve autosomal and sex linkage problems revealed additional trouble areas. It was evident that being able to work a linkage problem on paper was much different from being able to work one with the microcomputer. The student may have known the definition of linkage and been able to use data to calculate percent crossovers, but this did not necessarily imply he had meaningfully learned the concept. The following problem required a thorough knowledge of the concept linkage.

> Problem 5AC: In cats, there is one gene, with the alleles orange and cream, that controls coat color. Orange is dominant to cream. A second gene controls tabby striping; mackerel stripes are dominant to blotched. Use CATLAB to explore whether there is evidence for any linkage between these genes. What cross is the most efficient way to solve this problem? If no linkage, what result is expected? If linkage, what result is expected?

To answer these questions, the students had to interrelate linkage with the component concepts of gamete formation, offspring production, testcrosses, alleles, and the relationship between genotype and phenotype, among others.

A variety of difficulties were experienced with problem 5AC. Of the 20 students in the microcomputer group, 19 tried the problem. Four of those 19 did finally arrive at a correct solution. Using testcrosses and interpreting their results was a major obstacle here. In the interviews, the following misconceptions were uncovered and prevented students from completing the problem.

1. The two alleles for one trait could be linked.
2. The results had to reflect Punnett square results.
3. The dominant genes for two traits had to be linked, likewise for the recessives.
4. When two traits occurred together they were linked.
5. Linkage of genes did not imply linkage of their alleles.

Such misconceptions confused the students and prevented them from effectively answering the questions posed in the problem. These became obvious as the students interacted with the microcomputer. Similar situations were seen with other problems as well.

When it came to working a sex linked problem, the microcomputer served 2 specific purposes. (1) It demonstrated one reason why a student would have difficulty interpreting results. (2) Random data could be provided to permit testing an hypothesis. Excerpts from interviews on question 4C illustrate this.

> Problem 4C: The gene for orange or non-orange (usually black) coat color in cats is sex-linked. A black male is mated to an orange female. Use CATLAB to determine the genotypes of these parent cats and their offspring.

Student A20 used X's and Y's when discussing how he was going to plan his attack on the problem. But, when he worked out sample crosses on paper, he did not rely on X's and Y's. Perhaps this was also the reason why he missed a sex linked problem on the GAT-2 and on the final exam.

> I: "Alright. Now, in the Punnett square you've got offspring that are capital B, little b."

A20: "Um-hm."

I: "Are those males or females?"

A20: "Either one....they could be either one...except that, in the female....I mean....they would both be present....so there would be either....they could be either color, or a combination of the 2......and in the male only 1 would be present.....so there could be no combination of the 2. Which is what my results showed."

I: "Ok, I guess one of the things that bothers me the most in your Punnett square is that you can't tell males from females in there. But yet, when you look at your data sheet, you obviously have differences in the males and females. As you pointed out to me, you never had a black and orange male. Do you feel it's necessary, when you do a sex linked problem, to show some kind of sex identification?"

A20: "Uh.......I don't think so. That didn't seem to be it in this case."

I: "Suppose you were asked to make a ratio in this problem, of the different kinds of males and females? How would you do that?"

A20: (pause)..."Ah.....I don't really know."

Student A4 shows a typical example of testing an hypothesis with the micro-computer.

I: "So, have you checked out enough crosses here to substantiate the model that you've developed that black females must be BB, black males are B, orange females are OO, and black and orange females are BO? (pause) What would a black and orange male be?"

A4: "I haven't seen any black and orange males."

I: "Using your model, should you?"

A4: "No, using my model, there should not be black and orange males."

I: "And you haven't seen any and you've generated 40 cats here, right?"

A4: "Yeah, right. I haven't seen any and that could be because there's something I'm not taking into account....40 cats isn't a conclusive number, but it does fit in with the model I've proposed."

I: "Are you saying to me that you're done with this problem, or do you think you need to do something more?"

A4: "I could go back to the beginning and try to program in a black and orange male. And then work with that and try to come up with a different hypothesis if the computer will generate one."

I: (Later) "Ok, what happened?"

A4: "I tried to program in the black and orange male and the computer tells me that this cat is a very rare male tortie, [illegible] would be expected to be sterile. Ok, it's sterile... let's see....what do I remember about sterility...well.... it shouldn't occur, it's very rare, so I think that it doesn't conflict with my theory. Let's see, how would it happen......good question."

I: "Apparently there is actually such an animal, according to this."

A4: "Yes, there is such an animal."

I: "Could you account for such an animal with your model?"

A4: "I'm trying to."

I: "It may involve something that you haven't studied yet, although it is in the unit."

A4: "Would it have something to do with this type of thing where there's an extra sex chromosome?"

I: "Yes, it could."

A4: "Ok, if it could, assuming that it could have something to do with that. If it had an extra X chromosome, if it was XXY, and it had 1 X^O and 1 X^B, and since the O and the B are incompletely dominant over each other, then they would both show and this animal would be sterile and it wouldn't pass that one."

I: "So where are we in the state of affairs with your model?"

A4: "Well, my model seems to be OK for the number of cats I've generated."

SUMMARY

This has been an integrated attempt to identify concepts which were weak, missing, or misinterpreted prior to and during instruction in Mendelian genetics and meiosis. Table 2 summarizes results from the problems cited in this paper. The microcomputer as an educational research tool was also examined.

Four areas which consistently presented difficulty were considered. It was found that students depended too heavily on the Punnett square method of problem solving, practiced little integration of concepts, did not consider alternative interpretations of the data, and were dogmatic in their reliance on the Mendelian ratios. Lack of problem solving success seemed to result, in large part, from the students' inability to use analytical reasoning, or inexperience in doing so. Unless prompted, many students would not consider alternate explanations of their data. Likewise, they would not, on their own, test other viable hypotheses for a problem.

It is realized that analyzing cognitive structure with the aid of a microcomputer is in the infancy stage. However, several observations can be made.

1. To reveal the most information about what the learner knows and what difficulties he is having, both the microcomputer and conventional problem sets need to be accompanied by an interview.
2. Random generation of data by the microcomputer more easily permits in-depth examination of levels of knowledge and reasoning rationale.
3. The microcomputer forces the student to participate in his own learning. Because the data may conflict with and challenge his notions, he must reconsider what he really knows and reconcile any differences.
4. The microcomputer requires analytical thinking both in interpreting unexpected results and designing experiments for hypothesis testing. Many relevant concepts must be brought to bear in these instances.
5. It is possible to correlate the identification of weak, missing, or errant concepts among various assessment techniques, including the microcomputer (Table 3 and Figure 3).
6. There are positive affective aspects of using the microcomputer. Generally, students responded favorably when

questioned about working with realistic data. The comments of one student are typical in this respect. "The program is so much fun! It allows the students to become involved with the problems and approach them in a very different way. This approach is very demanding in testing the student's knowledge."

Data derived from interviews of students while using the microcomputer were judged to be richer in content for identifying cognitive structure than that obtained from interviews about non-microcomputer problems . This was, in large part, due to the format of the microcomputer problems.

The CATLAB program is an excellent program. The reader should note that difficulties experienced by the students as they work through the problems are not indicative of program weaknesses. They do suggest CATLAB could be used diagnostically as a teaching and research tool.

These findings suggest some considerations for the classroom. Deliberate attempts need to be made to integrate meiosis with Mendelian genetics and to explain gamete formation, genotypes, and phenotypes on that basis. A greater teaching effort is needed at the chromosomal level of inheritance: a conscious effort must be launched to link chromosome behavior to gamete formation and gamete composition to any algorithms taught. I would suggest that genetics problems should be worked FIRST on the basis of chromosome behavior. Models, diagrams, and examples should be used. This initial genetics instruction should be presented PRIOR to using text material relating to Punnett squares.

A thorough understanding of the meiotic process and how it relates to genetics problem solving MUST be established in the students' mind. Once this is done, it will serve as an anchoring framework for the variety of problem situations and results the student will encounter. Building on these concept relationships from the chromosomal level will be more meaningful and serve the students well in integrating related concepts, e.g. consequences of linkage and crossing over, multiple alleles vs. multiple genes. The Punnett square and the "tree method" of multiplying probabilities may be useful algorithms which save time, and may even produce correct answers in certain contexts. However, it is obvious from the work reported here, the student loses sight of what is really happening when he uses these techniques. There is a vast difference between getting the right answer and achieving understanding. Table 4 presents suggested impacts on learning statements based on typical misconceptions.

Stewart (1982) summarizes the 15 most important and difficult biology categories (of 55 provided) as determined in a recent rating survey of 100 high school science teachers. That summary shows mitosis/meiosis, Mendelian genetics, and the chromosome theory of heredity appearing within the top 11 of the 15 categories in both importance and difficulty ratings. It is obvious from this data and the research reported here these areas are much in need of further efforts toward understanding the techniques used and obstacles encountered by the learner as he struggles with the concepts. The desired form and level of sophistication for the concepts to be acquired must be identified, and the methodologies for teaching and learning those concepts must be improved.

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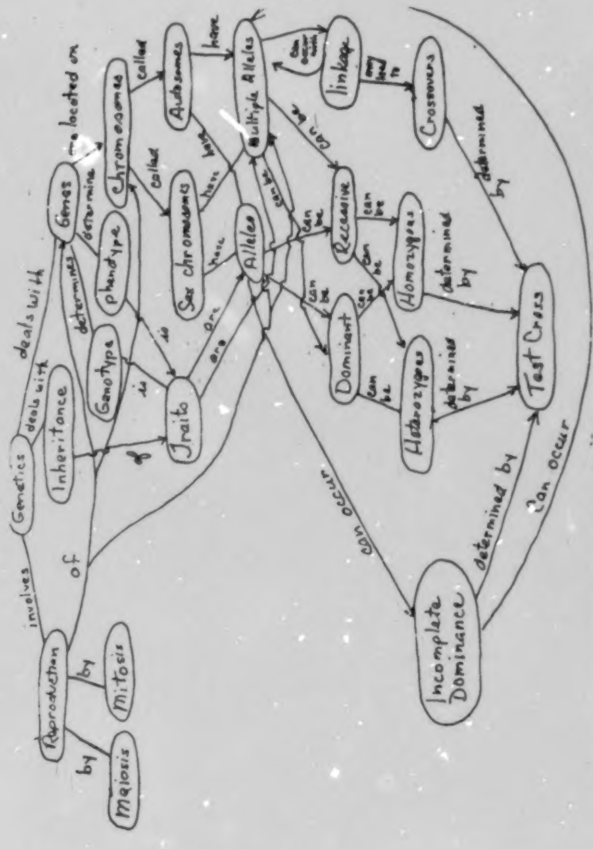
Genetics
involves
deals with
deals with
Reproduction
Inheritance
Genes
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Incomplete Dominance
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Fig. 2 Concept map made by student A7 at end of study. When map was produced, student had passed units on meiosis and Mendelian genetics with at least an 85%. See text for further discussion.

Table 2 Misconception Summary from Selected CATLAB Problems

Problem Number	Type	# Completing w/o prompting	Misconceptions Noted
1C	determining genotypes-one trait crosses	8 out of 19	1.Kept expecting exact ratios of of Punnett squares. 2.Conclusion based on limited data: other explanations not considered. 3.Predominant phenotype is dominant: conclusions based on limited data. 4.Assumed genotype w/o checking.
2C	incomplete dominance	7 out of 20	1.Heavy reliance on Mendelian ratios. 2.Drawing conclusions on limited data 3.Multiple alleles confused with multiple genes. 4.Confused incomplete dominance with other concepts, e.g. epistasis.
5AC	determining autosomal linkages, 2 traits	4 out of 19	1.Two alleles for 1 trait could be linked. 2.Results had to reflect Punnett square results. 3.Dominant genes for 2 traits had to be linked together. 4.If 2 traits appeared together, they were linked. 5.Linkage of genes did not imply linkage of their alleles. 6.Various interpretations of testcross. 7.Conclusion on limited data. 8.Assumed genotypes. 9.If no linkage, each allele is in separate gamete.
4C	sex linkage with incomplete dominance	4 out of 17	1.Did not designate male or female. 2.Tried placing allele on X and Y. 3.Didn't realize incomplete dominance and sex linkage could occur together. 4.Drew conclusions on limited data. 5.Sex linked meant it could be on either X or Y. 6.Confused with other concepts, e.g. collaboration.

Figure 1 Examples of Parallel Problems

Category: Incomplete Dominance

Microcomputer Problem 2C

A litter resulting from the mating of two cats, both of which have only some white in their coats produces 2 kittens with no white, 1 kitten with extensive white, and 5 kittens with only some white. Using CATLAB, what would be the simplest way of explaining the inheritance of regions of white on the cat's coat? Also, from the CATLAB program, determine the parent genotypes.

Textbook Problem 2K

If the litter resulting from the mating of two short-tailed cats contains 3 kittens without tails, 2 with long tails, and 6 with short tails, what would be the simplest way of explaining the inheritance of tail length in these cats? Show genotypes.

Category: Two-trait Cross

Microcomputer Problem 3C

In cats, blotched tabby pattern and cream coat color are produced by 2 recessive genes located on different chromosomes. The mackerel tabby pattern and orange coat color are produced by the dominant alleles. Suppose a cream blotched tabby male is crossed with a homozygous dominant female. Use CATLAB to determine the types of progeny expected. What are the genotypes of the F1? If the F1 are permitted to mate randomly among themselves, what kinds of progeny are produced in the F2? Produce repeated litters until you have at least 16 kittens. Are there other phenotypes you would expect? If so, what are they? What phenotype ratio do you have? What phenotype ratio did you expect? Of which genotypes can you be sure?

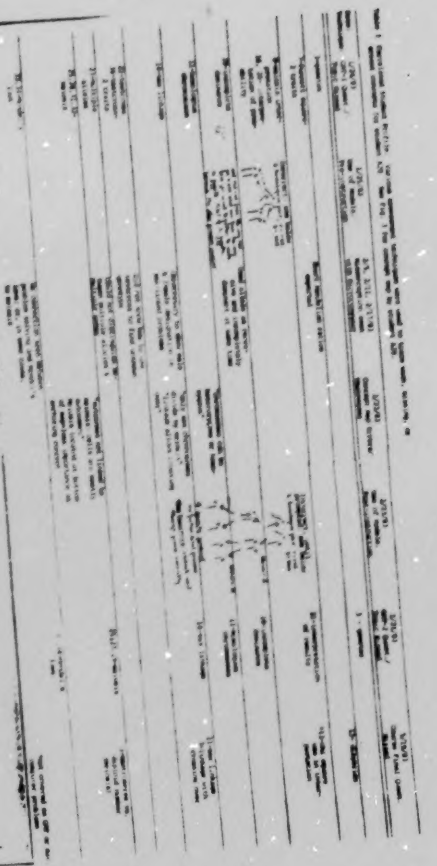
Textbook Problem 3K

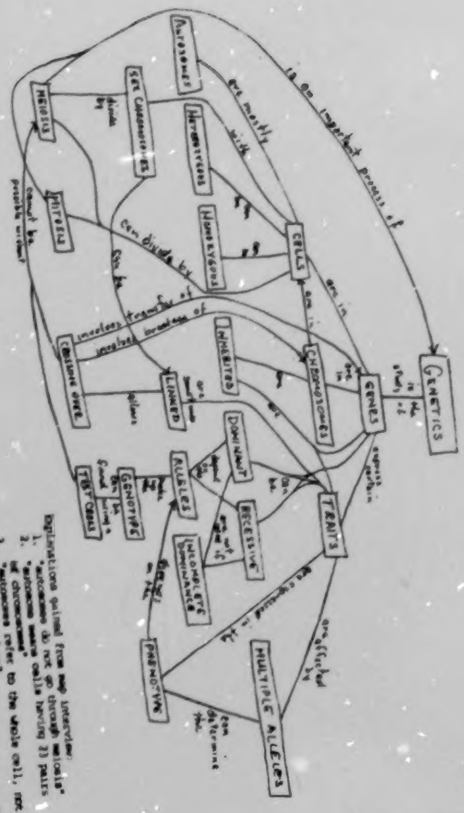
In the fruit fly Drosophila melanogaster, vestigial wings and hairy body are produced by 2 recessive genes located on different chromosomes. The normal alleles, long wings and hairless body, are dominant. Suppose a vestigial-winged hairy male is crossed with a homozygous normal female. What types of progeny would be expected? If the F1 from this cross are permitted to mate randomly among themselves, what progeny would be expected in the F2? Show complete genotypes, phenotypes, and ratios for each generation.

Table 1 Vocabulary Knowledge Determined in Pre-Instructional Interview

Term	Number Correctly Defining* (N = 40)
phenotype	35
zygote	34
genotype	33
gametes	32
homozygous	28
incomplete dominance	28
heterozygous	27
homologous	19
testcross	13
autosomes	11
Mendel's laws	7
meiosis I vs. meiosis II	7
sex linked	5
alleles	2
crossing over	0

*If student definition was more right than wrong, it was counted as 'correctly defined'.




GENETICS
is the study of
GENES
express certain
are in
CELLS
CHROMOSOMES
TRAITS
are affected by
MULTIPLE ALLELES
can determine the
are mostly
with
AUTOSOMES
HETEROZYGOUS
HOMOZYGOUS
INHERITED
DOMINANT
RECESSIVE
can be
INCOMPLETE DOMINANCE
are expressed in the
ALLELES
LINKED
PHENOTYPE
SEX CHROMOSOMES
divide by
can divide by
involves transfer of
involves breakage of
CROSSING OVER
allows
GENOTYPE
can be found using a
TEST CROSS
MEIOSIS
MITOSIS
cannot be possible without
is an important process of

Explanations gained from map interview:
1. "autosomes do not go through meiosis"
2. "autosome means cells having 23 pairs of chromosomes"
3. "autosomes refer to the whole cell, not just the nucleus"
4. "sex chromosomes can be linked" means "traits can be linked on sex chromosomes"

Fig. 3 Pre-interview concept map by student A20. Map was made after student had completed the study and had passed units on meiosis and Mendelian genetics with at least an 85%. See Table 3 for comments.

Table 4. Possible impacts of misconceptions on learning.

CONCEPT AREA	TYPICAL MISCONCEPTION/ INTERPRETATION	IMPACT ON LEARNING
Understanding meiosis	Each gamete contains ½ the no. of chromosomes. Only sex chromosomes involved. Only one division takes place.	Leads to gamete errors = problem errors = resorts to Punnett sq. or tree method. Contributes to belief that meiosis important in limited cases. Difficulty in accounting for all genetic variations. Interferes with interpretation of mechanisms of phenotype variability.
Relating meiosis to problem solving	No relationship No relationship, except when linkage and/or x.o.	Student regards Mendel's Laws as unimportant. Ignores concepts of segregation & independent assortment, Contributes to unclear relationship between phenotypes and chromosome behavior.
Use of Punnett squares	Represents reality rather than probability	Leads to rejection of alternative explanations. Leads to dogmatic reliance on Mendelian ratios. Promotes rejection of correct interpretations.
	Letters outside squares represent parents.	Incorrect solutions presented for two trait problems. No integration of relevant concepts of chromosome behavior and organizatic f Punnett square.
	Must be squares - only 2 or 4 gametes produced.	Inability to interpret or hypothesize unexpected results.
Tree method of problem solving	Intermediate combinations represent gametes.	Contributes to misconceptions of chromosome behavior and gamete formation.

Thinking In
Two Worlds of Knowledge

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The educational community can now call upon a valuable accumulation of research-findings concerning children's out-of-school notions about scientific matters. The primary intention of this paper is neither to summarise these nor to add to them, although the course of the argument may include some elements of each. Its real purpose is to explore the social and epistemological differences between such prior, unspecialised knowledge, and the formal explanations which we teach in science lessons. This analysis is of immense practical importance because it suggests that our students may well possess two radically different ways of thinking about the everyday world,at one and the same time. If true, this cannot but present the tasks of the teacher and pupil in quite a different light. Before students can begin to apply scientific principles to a practical problem they will need to make a choice between alternative knowledge systems, which is all the more difficult for being effectively hidden.

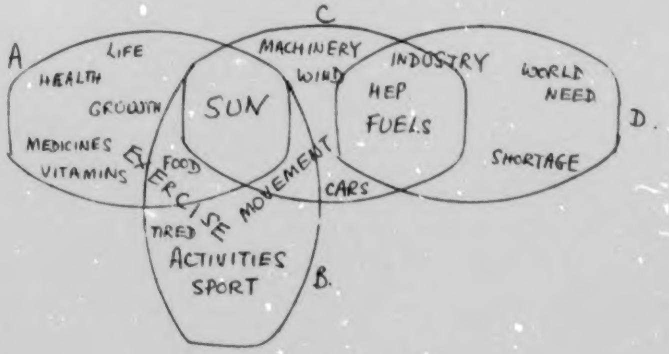
Life-world Knowledge

For common words such as force, energy, food, atom, heat, or light, it is to be expected that students will already have acquired a whole repertoire of meanings long before they enter school. These words are used in everyday conversation where their meanings are not defined, but are expected to be understood by others. They are a part of that chaotic body of knowledge called "common sense" which most philosophers have wisely chosen to ignore. One exception to this is Stephen Pepper who, in World Hypotheses (1942), described it as not definitively cognizable, secure, and cognitively irritable, three characteristics that we shall return to later.

In Structures of the Life-World (1973) Schutz and Luckmann present a very detailed phenomenological account of the complex origins and nature of such knowledge. Briefly, they describe a process by which past experiences are loosely typified and added to a general stock of knowledge in meaning-structures which are then either reinforced or obliterated by social and linguistic usage. In what Husserl has described as the "natural attitude of the life-world", such meanings will seem to be complete, confirmed by everyday experience, and oblivious to inconsistency.The reason for this appears to be that local situations are only in limited need of explanation, thus conflict between contradictory elements of life-world knowledge is hidden by their relevance to different contexts.

This theoretical perspective has been most illuminating when applied to an exploration of young students' life-world knowledge about energy. In the first phase of this a very simple questionnaire was administered to about 300 students in grades 6 to 8. They were asked to write three or four sentences showing how they might use the word energy.Figure 1,below, shows the four main "provinces of meaning" into which their usage fell.

FIG I



In province A there is a typification of energy as health or the life-force, in B as human activity, in C as inanimate movement, and in D as a world-wide resource in short supply. In the areas of overlap lie those items which may be explained by one meaning structure, ("the sun makes things grow for food to give us energy") or another, ("the sun is the source of life and energy" or "solar energy could work our machines.")

Closer inspection showed several interesting features. There was a significant difference between the contributions of girls and boys, with the former giving more meanings referring to to human energy in general, and province A in particular. Perhaps this should be interpreted in line with the girls' greater commitment to caring, so well described in *In a Different Voice* Gilligan (1982).

A second surprise was the elements of contradiction which occurred, sometimes within one and the same set of sentences:

Exercise builds up your energy (Health, life-force)

Exercise uses up your energy (Human activity)

The second phase of exploration, using class discussion, showed that this was no mere quirk or eccentricity. In all these classes there was always a sizable number of pupils ready to give open allegiance to *both* these views, remarking, in a modern paraphrase of Schutz and Luckmann's words, "it just depends on the circumstances".

During this class discussion phase it also became clear that there were wide areas of inter-student agreement, and none at all of misunderstanding. Meanings conveyed through sentences, written in effective isolation, obviously had broad social currency. There were no cases of idiosyncratic usage, which might have been acquired by personal trial-and-error, in the total of nearly 1000 examples (although some, like "the monster threw an energy bolt", defied any system of classification).

The written survey allowed students to make a generalisation in answer to the question, "What is energy?". At first this produced no more than some vague

synonym, but increase of age and hence the range of meanings available to the children, swelled the number of incipient operational statments such as "It is in all things that move" or "It makes everything work". There was great variety in the words used and no significant correlation between the belief that energy is a measurable quantity and the ability to construct such generalisations. Rather than dignify this as "Children's Science" it would seem more realistic to accept it as no more than a readiness to typify qualities, *not concepts* (like bigness and heaviness, *not* volume or weight) out of an experience of linguistic use.

Comparing the Two Knowledge Systems

Using these reaerch findings, and others, an attempt will now be made to point up some of the major differences between this life-world knowledge and that of the science domain.

(a) *Life-world knowledge is inconsistent and context-bound* (cognitively irritable)
The limitations of space dictate that only a few of the researchers who have noted this characteristic may be quoted here.

> "Students never... notice that a propostion they have used to explain the motion (of an object) in one of the situations is directly contradicted by a proposition that they use to explain the motion in another situation."
>
> Champagne et al (1980)

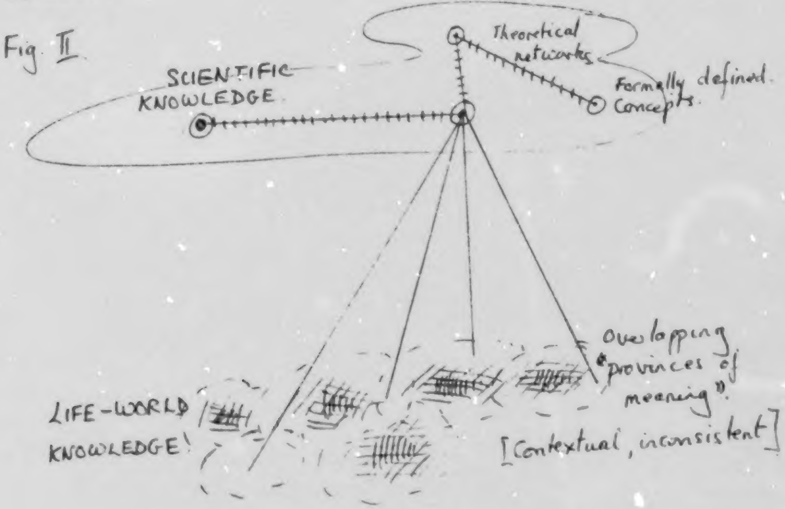
Similar comments about the life-world knowledge on heat are made by Driver and Russell (1982) and by Pines (1978) on the concept of living, - "concepts are highly situational and context-bound".

The contradistinction between this, and universal scientific laws, is only too clear. This must present our students with an initial hurdle if they expect from science no more than maxims of the kind - "Too many cooks spoil the broth" - which may be true for soup-making , but is not for peeling potatoes !

(b) *Life-world knowledge is not symbolic* (not definitely cognizable)
Because scientific knowledge is completely decontextualised, it is free to speak of "kinetic energy" rather than running children, rushing wind, or driving rain.

It constructs formalised symbolic concepts which go far beyond the abstract generalisations mentioned in the preceeding section. Such scientific concepts are tightly, consensually, defined forming part of a theoretical network which overarches the everyday world of experience for the purpose of providing a causal explanation.

Fig. II


SCIENTIFIC KNOWLEDGE
Theoretical networks
Formally defined Concepts.
Overlapping "provinces of meaning".
LIFE-WORLD KNOWLEDGE
[Contextual, inconsistent]

Explanations of this kind do not exist in life-world knowledge. Even when "typifications deriving from experience or language use, are expanded beyond their usual province of meaning, they operate more by analogy than by symbolic reasoning. Adults interviewed in the energy project often extracted the "root metaphor" (Terwilliger 1968) of 'liveliness' from the meanings of energy to use it in such terms as "mental energy" or even "psychological energy". The intention seemed to be more effective description than explanation. Engel (1981) draws attention to the way 'suction' is used to explain the rising of a liquid in a drinking straw and a syringe, without any attempt to clarify the term beyond the circularity of meaning-and-explication.

(c) Life-world knowledge is well socialised (secure)

Meanings thrive on continual use. No doubt this is also true of scientific meanings, but when these are confined to a couple of periods per week during a few years of school teaching, the advantages must be all on the side of the life-world meanings that are daily reinforced. Cross-linguistic studies, such as those of Duit (1980) on German, Swiss and Phillipino students, and Ross and Sutton (1982) on English and Tiv-speaking Nigerian students, demonstrate very effectively this blanket socialisation of meaning produced by language use.

This factor produces a problem for the teaching of science which is not always recognised. Meanings which are in daily use cannot be obliterated by science lessons, however convincingly presented. Even when the concepts and theories of science have been learnt, the older meanings, and loose explications of the life-world, will still linger on. All of us continue to speak of "cold creeping in", "throwing glances around the room" and "feeding a plant through the soil" however proficient we are in phyics and biology. This implies that our students will acquire, through their instruction in science, a second domain of knowledge which is radically different from the first but coexistent with it. Under these circumstances we shall want to know if they are aware of these two competing sets of meanings and, more importantly, how they decide which one to use during problem-solving exercises.

Student awareness of the Two Domains

Awareness is a condition which spans wide boundaries. We might search for it by asking "Is there any difference between the scientific meanings for words like force, energy and work, and their everyday meanings ?". Such a question seems to claim an affirmative answer. Alternatively we could demand an articulation of the two sets of meanings. Not only does this beg the question, but the cluttered meanings of the life-world are not definitively cognizable, and rote repetition of scientific definitions carry little conviction. In a more ambitious and tricky mode we mightpresent students with abrupt transitions between the two domains of knowledge to find out if they can detect, identify and correct them. Two sets of experiments have been carried out, along these general lines, and will be briefly reported here.

(a) Test and interview about familiar words

Seventeen middle ability Grade 9 pupils who had just completed a short test, which included questions on the formal definition of energy and the conservation prinicple, were asked in interview whether they thought that the physics meanings of these words were the same as those in general use. Their answers were than compared with the correctness of the definitions they had given in the test. Those who had got these wrong were reminded of the right answer before they gave a comparison of meanings.

"CONSERVATION"		(Test)	
		Right	Wrong/Omitted
Everyday Meaning (In interview)	Knew it	0	9
	Did not	4	1

(N= 14)

"ENERGY"		(Test)	
		Right	Wrong/Omitted
Everyday Meaning (In interview)	Same	1	3
	Not sure	2	1
	Different	9	1

(N = 17)

Despite the smallness of the sample these results do suggest that everyday meanings form a conceptual trap. Familiarity, it seems, breeds insensitivity to a change of usage. The only way to avoid this pitfall is via a clear appreciation that physics knowledge is different. The alternative approach, by which students are encouraged to discuss and expand their personal everyday meanings for such words so that they may contrive to capture a scientific flavour (Pope 1982) may, in the end, do them no great service.

(b) Discrimination tests

The second experiment involved 75 grade 9 students of varying ability as judged by a school-based examination. They were asked to read some sentences, to decide whether any were wrong and, if so, to put them right. Four of these ran as follows: -

1. Energy is measured in Newtons.
2. The kinetic energy of a car turns into friction when it brakes.
3. Work is measured in Joules.
4. The water at the top of a waterfall has potential energy which turns into spray at the bottom.

There were, in all, nine such sentences of which these form a representative sample. Would pupils of different abilities be able to perceive the incorrect transitions between symbolic and life-world knowledge in sentences 2 and 4, any better than theycould sort out those relating to rote learning ?

	Ability groupings			
	1	2	3	4
% success in (1)	96	60	88	50
% success in (2)	36	14	13	3
% success in (3)	100	68	79	76
% success in (4)	100	84	32	3

These data suggest that all the pupils, especially the less able, find less difficulty in questions (1) and (3) which depend upon rote learning than in the discrimination sentences. The latter, numbers (2) and (4), produce a much better spread of results matching the pupils' abilities in the examination which contained a range of more traditional problem-solving questions. It could be tentatively concluded from this that discrimination between the two domains of knowledge plays an important role in success in school physics.

Moving between domains of knowledge

For accounts of empirical studies of students' transitions between these domains the reader is referred to Learning about Energy :How pupils think in Two Domains Solomon (1983) and Messy, Contradictory and Obstinately persistent Solomon (in press). Here, by way of a conclusion, an attempt will be made to link this model of science learning with theories from other disciplines, from education, and from science itself.

In the construction of Artificial Intelligence, the higher level "world View" both includes, and allows selection from the multitude of possible local analyses.

> "Successful programs in AI are not solipsistic ones which dream up their own world entirely. Rather they combine world model knowledge with more small scale inspection of local context... which we have called contextual, structural and monadic." De Mey (1982)

Where the higher domain is devised by a human culture to deal with common misdemeanours, its connection with the contextual patterns of habit and custom will not be so clear. Nevertheless we can still detect the characteristics of the life-world and the symbolic.

> "Thus the precepts of custom, very close in this respect to sayings and proverbs, have nothing in common with the transcendent rules of a juridical code: everyone is able, not so much to cite and recite them from memory, as to reproduce them fairly accurately." Bourdieu (1977)

In the great edifice of genetic epistemology which was the life work of Jean Piaget it is possible to recognise a rather similar distinction between two kinds of knowledge. One is "knowing how" in a particular context, the other "knowing that" by propositional and essentially symbolic thought. In *Success and Understanding* (1978) Piaget stresses the radically different learning movements in preoperational thought and formal thought, the former moving from the periphery (contexts) to the centre (concepts) and the other from the centre to the periphery.

Bearing in mind this postulated difference in movement between context-based experience and formal theory, we may now turn to the logical positivist theory of science.

> "A scientific theory might therefore be likened to a complex spatial network. Its terms are represented by the knots, while threads connecting the latter, in part, to the definitions and in part to the fundamental .... theory. The whole system floats, as it were, above the plane of observation"
>
> (Hempel 1952)

This fanciful picture bears an uncanny ressemblance to figure II depicting the relation between life-world and symbolic knowledge. What such hypothetico-deductive theory of science suggests is that movements between the two domains are not at all symmetrical. Moving upwards from the realm of observation and commonsense knowledge to the abstract and symbolic requires hypothesis, always a tricky feat, even when it has been demonstrated by previous science instruction. Moving "downwards", however, from the symbolic to the everyday only requires the simplest process of deduction, of parading of concrete examples to illustrate a given abstract concept. It has been shown, in both my own work and that of Viennot (1979), that physics students, even the most able, experience considerably more difficulty in solving questions which have been set in the life-world and need transition to the learnt world of physics theory, than they do in solving problems in an abstract setting.

In this paper due respect has been paid to the rich metaphorical meanings of everyday life. We could not eradicate them even if, in misguided zeal for science education, we so wished. The splendid edifice of modern science is indeed the cultural legacy of all our students and we need to teach it with all the flair and competance we can muster. Nevertheless this approach shows that it is a foreign world which many will find difficulty in entering while the familiar undemanding clutter of the life-world still provides its alternative ways of thinking.

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IMPLICIT STATEMENTS IN PHYSICS:STUDENTS AND CONSTANTS

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INTRODUCTION

The present paper is a part of a group of studies whose goal is to describe the "natutal" reasoning of physics students in as simple and predictive a fashion as possible,the object being to provide students with a clearer image of their own intuitive tendencies in order better to master them.In this effort of description, the importance of specific contents is seen to be considerable; thus,many studies of students'reasoning are focused on a particular domain of physics: mechanics, electrodynamics,heat and temperature,etc.This choice of content,while highly relevant, must not be exclusive:other angles of attack might reveal characteristics of reasoning which are less dependent on a specific content.The work which I present here is addressed to this issue.

Under the general heading of the implicit in physics, this study attempts to clarify the meanings that students attach to the common type of statements used by students themselves and by instructors.Our object is not to call for a fully explicit style of expression, which would be both deceptive and impracticable.Rather,we attempt by this investigation to observe some important components of reasoning and to bring these clearly to the attention of teachers and students.In the conclusion,I will suggest some pedagogic advantages of helping students to grasp better their own reasoning process.

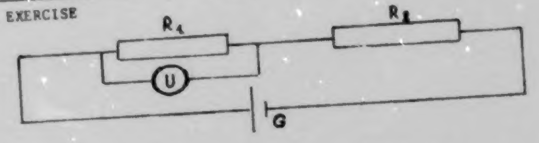
Here we are specifically concerned with functional reasoning in physics.This expression is better understood by comparing two methods:

-one,purely numerical,where a given expression U=RI (between the voltage U at the ends of a dipole,the resistance R and the intensity of the current which flows through it) is seen simply as a tool for calculating one numerical value by means of the others;

-the second,functional,where the notation U=RI carries other significations: the voltage is a function of two variables, it increases with the intensity for a given resistance, and it increases with the resistance for a given intensity.

The textual analysis proposed in Figure 1 shows how strong a tendency first year university students still have to fix one of the two variables in order not to have to considerthe function except in terms of a single other variable.Reinforced here by some characteristics of natural reasoning in electrodynamics,which readily consider.a battery as a "source" of constant current[1], this tendency can be seen in many different contexts: the relation between speed,distance covered and travel time,for example.

READ THE EXERCISE



We increase R_1. We note that U also increases. Explain why.

READ THE RESPONSE OF A STUDENT:

$U = R_1 I$,since R_1 increases, U increases

CRITICIZE THIS RESPONSE.

Is it correct? False?(Why?) Incomplete? (What is missing?) Rigorous?

CORRECT RESPONSE:

One should wonder if the intensity varies when one increases R_1 (in fact,it decreases)

FREQUENT RESPONSE:

Half of the students ,in both categories,accept the reasoning proposed.

Fig. 1: a textual analysis proposed to students
in the last year of secondary school (N=25)
in the first year at university (N=25)
(following a test of J.L.Closset) (1)

A general preoccupation with functional reasoning and the difficulties linked to the functions of several variables led me to make a more focused study on what might seem at first to be paradoxical in this context, the theme of constants.

I "NUMERICAL" CONSTANTS OR "FUNCTIONAL" CONSTANTS ?

The term "constant" can in fact cover a range of meanings.At one end, numerical, the word "constant" operates as a common noun nearly synonymous with "number", more or less useful to know, ranging from one simple feature of an object, like the mass of the earth, to so-called universal constants, like Ɲ or c .At the other end, functional, we are dealing with an adjective that has lost its noun - a constant function of such and such variables - the important thing being the list of these variables which one might think a priori to affect the "constant".But when one attempts to specify those variables that are "without effect" on the physical quantity being considered, one usually perceives that this quantity is dependent on other variables,such that a fairly complete functional formulation ends up having two subdivisions: "interesting independencies" and "dependencies".Figure 2 gives an idea of the way in which such an explicit formulation clarifies and completes the type of statement commonly practiced in physics.

THE SPEED OF LIGHT IS A CONSTANT

The speed of light in vacuum DOES NOT DEPEND ON the frequency the frame of reference	The speed of light DEPENDS ON the index of refraction of the medium the frequency (except in vacuum)

OHM'S LAW

AT A CONSTANT TEMPERATURE,THE RESISTANCE *
OF A METALLIC CONDUCTOR IS A CONSTANT

The nature,dimensions and temperature of a conductor being fixed,its resistance DOES NOT DEPEND ON the tension U applied at its ends the current which flows through it	The resistance of a conductor DEPENDS ON the nature of the conductor its dimensions its temperature

Fig.2 : two commonly-made statements explicated and completed

* See the statement ptoposed for the Ohm's law by O'Sullivan (2)

II SOME EXPERIMENTAL FACTS

The question we raise is this: how do students situate themselves with regard to statements heavily weighted with the implicit? Which of the possible meanings do they prefer? What further information do they need?

Conducted with first year university students, our study uses the statements shown in Figure 2. The questions posed are of the following kind: Does this statement seem to you clear and unambiguous? Does it seem incomplete? If so, what additional statements seem necessary? merely useful? Would you like to re-state it? If so, how?

The most striking features of the results are summed up in Tables 1 and 2.

PRINCIPAL CHARACTERISTICS OF THE COMMENTS OF STUDENTS
ON STATEMENT 1 (Table 1)
AND 2 (Table 2)

"The speed of light is a constant"

	N=32 Gembloux * 1st year Univ.	N=35 Gembloux 2nd year Univ.	N=27 Paris VII 1st year Univ.	N=100 E.S.I.E.A** 1st year Un.
it DOES NOT DEPEND ON...	28%	6%	18%	9%
in particular: the frame of reference	0%	6%	15%	3%
it DEPENDS ON...	50%	74%	85%	77%
in particular: the medium	50%	68%	78%	77%

Table 1

"At a constant temperature, the resistance of a metallic conductor is a constant"

	N=41 Gembloux 1st year Univ.
it DOES NOT DEPEND ON...	7%
it DEPENDS ON...	47%

Table 2

*Gembloux: Faculté des sciences agronomiques (Belgique)

**E.S.I.E.A.: Ecole Supérieure d'Informatique, Electronique et Automatique (Paris)

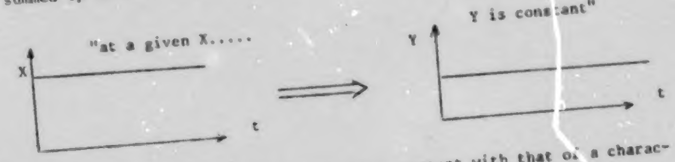
What one essentially notes is that the givens in question, the speed of light, or the resistance of a conductor, are not reduced, first and foremost, to simple numbers, like c=300,000 km/s, for example. The functional aspect is considered, but, paradoxically much more frequently with respect to the dependencies than to the independencies. That the speed of light depends on the medium is generally emphasized. What, then, might this quantity not depend on.. that is, in what way is it more "constant" than any other physical quantity? No student seems to raise this questions. Very few cite the property of invariance by change of frame of reference.

Similar observations can be made for the resistance of an ohmic conductor. Of the 41 students questioned, only one made spontaneous reference to the essential property of invariance with relation to the tension applied and the current which flows through it*. Two others mentioned an invariance in time. In contrast, one notes ample and precise information on the factors on which the "constant" did depend**.

If one now question more closely, and no doubt at a more hypothetical level of analysis, the way in which these dependencies are perceived and expressed, some further remarks can be made.

The expression that would seem the most natural is of the type: such a quantity depends on such other quantity. Very frequently, however, one notes the format - as in statement 2 - "such and such quantity being given, such and such other is constant" : "for a given medium, the speed is constant", "at a constant temperature, the resistance is constant".

This fact does not seem irrelevant - any more than does the low incidence (17%) of reformulation of statement 2 in the form "the resistance depends on the temperature". These two forms of expression are not equivalent. It is very likely that the form "$X = C^{te} \Longrightarrow Y = C^{te}$" is favoured because of the special role of time as an implicit variable in so-called constant functions. This leads us to the interpretation summed up in the following schema:



This interpretation connects the notion of a constant with that of a characteristic of the object, the object being itself defined by its permanence in time.

It clarifies a posteriori the predominance of concern about eventual dependencies, of which the following two comments give evidence:

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*provided that the temperature remains fixed

**the early stages of a study involving mathematics teachers reveals the same behaviour

" If the physical, climatic and chemical conditions are constant, the resistance of the conductor is constant.

" It is not easy to have an ohmic conductor. One must take into account external variations other than temperature.At a constant temperature, and at a given instant under given exterior conditions,the resistance of a metallic conductor is a constant".

Regarding these comments, one is tempted to sum up them as follows:

" If everything is constant, the resistance is a constant" .Evidently, this compact phrase deprives the initial statement of the sense it was supposed to convey (an invariance), but it certainly expresses another,which the student has given it: an object must be specified completely for its characteristics to be well defined.

We are thus conducted back to a conception of constants that is highly dominated by the numerical aspect.

III REGARDING INTEGRATION CONSTANTS

Another example of a weakly functional conception of constants shows up with regard to integration constants.These might be said to be functional from birth:they are constant functions of integration variables (and may depend on other variables). The graphic image that should be associated with them is a shift of the whole graph (additive constants in the calculus of primitives) or an affinity (multiplicative constants in the solutions of homogeneous differential equations).As we shall see, such a meaning, focused on the idea of one degree of freedom of the whole function, is often blurred by the usual technical concerns: Which calculus do these constants originate from? How to cancel them? In these concerns, the so-called "initial conditions " play a predominant role.Often the adjective "initial" seems to suggest a temporal variable,even if time is quite irrelevant to the problem.

Thus commenting on the statement:

" $E = C_V T - \frac{a}{V} + C^{te}$ " (where E is the internal energy of one mole of a real gas, C_V the heat capacity,T the temperature and V the volume)

a student declared : "one can calculate the constant at the initial time"

All this may not seem to be of great significance. But it must be kept in mind that it is not the same thing to look for a rumber " at the initial time","at infinity' or elsewhere, and to understand what this number is:a constant function of such and such variable, whose value can be fixed for any value of this variable.

This is clearly shown by results of the following exercise (summarized here):

" What is the meaning of the statement: "Potential energy is defined within a constant"? Calculate the potential energy of gravitational interaction between two masses m_1 and m_2 versus their distance r...Give for $r > R_T$ (R_T = radius of earth) the shape of the curve representing the potential energy U(r) of interaction between a mass m and the earth * in function of the distance r from the center of earth to m. One decides that $U(R_T) = 0$, which is unusual . "

Results obtained in first year at university reveal the following facts (N = 58) :

- The question : "what does the statement...means?" leaves very few students without an answer.Nearly all of them have an idea on this point.
- For half of them, this idea is linked to the method of calculus that gives rise tothe constant: " as every primitive is defined within a constant, it is natural that potential energy would also be within a constant " , and sometimes:"one always seeks to cancel the constant".
- After this, the freedom of choice of origin is cited (15%): "it depends on the place that one chooses for U = 0", "it depends on the level that one starts from".
- Only 12% refer to the heart of the question: "only the variations can be defined", "only the shape of the curve is important"
- 12% give aberrant interpretations :"potential energy does not depend on the travelled path", "another force intervenes", "that is to say in the potential energy, there is a constant like g or k".

Turning now to the operational questions, one notes that 73% of the students who give an expression of potential energy in the second question do not mention any arbitrary constant, and this apparently regardless of any explainations previously given about the statement " within a constant ".

Finally, 62% of the students are in a state of total perplexity when they have to shift the whole curve of potential energy (whether correct or incorrect is not the issue) to fit it with the point $r = R_T$, U = 0 (see Fig.3).Among the 10% whose answers show a correct procedure (even with errors of calculation), only one out of five tried drawing a graph.It is characteristic to find in response to this question,the graph of Fig.4: the condition U = 0 for $r = R_T$ is super imposed, instead of being substituted, to such usual refrains as " the origin of potentials is taken at infinity, or " U is a function of $\frac{1}{r}$ type and tends to zero at infinite distance"

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* The gravitational version of the Gauss' theorem has been previously recalled

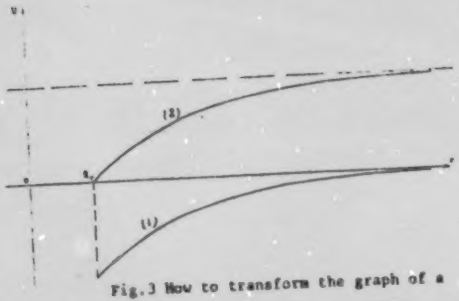

Fig.3 How to transform the graph of a quantity defined within a constant (here U:potential energy of gravitation of a mass) to fit it with a particular value (here $U(R_T)=0$ with R_T=radius of earth)

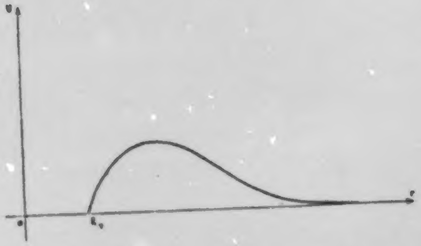

Fig.4 a typical mistake concerning the problem sketched in Fig.3

These examples should remind us that even so commonplace a statement as the inevitable " within a constant " cannot in itself convey its full (functional) significance.The acquisition of certain rote responses ("we cancel the constant" and the common methods of calculus ($U=-\int F.dr$) in no way guarantee a real comprehension of the matter, which in this case would be shown by the ability to transform curve 1 into curve 2, as shown in Fig.3.

CONCLUSION : A PLEA FOR TEXTUAL CRITICISM

We have seen that, in this domain as in others, there are certain typical features in students' reasoning. However, the most striking fact does not show up in the preceding tables.It is the fact of the reaction of the students tested,who pass,with regard to these exercises, from a skeptical bewilderment to discussions which, given the divergences, can become lively.True flashes of comprehension occur, resulting in reformulations whose clarity well indicates the progress made: " when one speaks of a constant, it is better to state what it depends on, but also what it does not depend on, here U and I."

This theme of constants, the clear comprehension of which paves the way to the understanding of the functions of several variables, is only one area among others which justify the use of exercises in textual criticism*. Students pass at least three quarters of their study time in the act of listening or reading.Why not to teach them to do so actively? Freed from the worries of calculus, they can use such exercises to concentrate their attention, for once, on the meaning of what they hear, copy and repeat each day.

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* for more details about textual criticism,see (3)

(1) Closset J.L.,1983 Le raisonnement séquentiel en electrocinétique,Thèse de troisième cycle,université Paris VII

(2) O'Sullivan C.T.,1980 Phys.Ed. 15,237-9

(3) L.Viennot,1982,Eur.J.Phys. 3, 174-180

Using Concept Mapping to Detect Interventions Effective in Improving Pre-Service Elementary Education Majors' Understanding of Science Topics

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Introduction

In this study, the effect of several different teaching strategies on increasing the overall quality of and reducing the number of misconceptions on pre-service elementary science methods students' concept maps is examined.

The students enrolled in the science methods courses at the University of North Carolina at Wilmington have, for the most part, very weak backgrounds in science. Since 1980 concept mapping has been used in the science methods classes to help students develop an understanding of the relationships among science concepts. During this time, I have been impressed with how this exercise has helped students become aware of what they understand and what they do not understand about a topic.

Purpose

By the spring of 1982 I wondered whether concept mapping could be used, not only to improve students' comprehension of the science topics they would teach children, but also to enable me to determine which of a number of possible activities would be most effective in improving the students' understanding of science concepts. Hence, the purpose of this study was to examine the effectiveness of different teaching strategies, singly or in combination, on elementary education majors' understanding of science topics as measured by the accuracy and complexity of the connections shown on the concept maps constructed by the students.

Procedure

Concept maps used in this study were constructed by elementary education majors enrolled in undergraduate science methods classes from the spring of 1982 through the spring of 1983. After the students had been taught how to construct concept maps and after they had been given several opportunities to construct concept maps, they were asked to construct the concept maps used in this investigation. The procedure that was followed is outlined below:

1. An alphabetical list of concepts related to a topic was displayed on a screen using an overhead projector.
2. Each student was given an envelope containing pieces of paper with a word or phrase typed on each piece.
3. Students were asked to arrange the pieces of paper to show the relationships among the concepts.
4. When a student was satisfied with his arrangement of the concepts, he was asked to diagram his arrangement on paper.
5. Once the concepts had been transferred to a paper, the students were told to:
    a. Circle each concept.
    b. Draw lines between concepts to signify relationships between concepts.
    c. Define the relationship between pairs of concepts by writing a verb or phrase containing a verb on each connecting line.

d. Indicate relationships between concepts on different strands of the map by drawing cross links.

e. Describe the relationship between pairs of concepts located on different strands by writing a verb or phrase containing a verb on the cross link.

6. If students did not know the meaning of a term or how the term was related to the topic, they were told to list the word on the lower right hand side of their papers and to omit the word from their concept maps.
7. Students were allowed to use additional concepts as needed to make their maps meaningful.
8. Some time later in the semester after at least one month had elapsed, the students were asked to construct another concept map on the same topic using the same alphabetical list of concepts and the same pieces of paper with a concept on each and following the same procedure.

Between the times at which the first and second concept maps were drawn, the science methods students experienced one or more of the following interventions:

1. Students received feedback about their concept maps:
   a. The instructor graded the concept maps and returned them to the students.
   b. The methods students were shown the instructor's concept map containing the same concepts.

   c. Misconceptions that had occurred frequently on students' concept maps were pointed out.
2. The instructor involved students in an inquiry activity to investigate the topic.
3. The methods students were provided the opportunity to teach the topics to children.
4. The methods students developed an instructional unit on the topic.

Pre and post concept maps were graded giving points for the number of concept terms used in the map, the number of levels in the map, whether lines indicating primary relationships between concepts were drawn, labeled, and were accurate, and whether cross links were drawn indicating relationships between concepts on different strands of the map (See Table 1. Criteria Used When Evaluating Concept Maps).

Results

The questions that were investigated and the results obtained from each study are summarized below and in Table 2. The first question I asked was:

1. Is the use of pre and post concept maps a valid measure of the effect of different teaching strategies on science methods students' understanding of a science topic?

In order to evaluate the validity of using pre and post concept maps to detect changes in students' understanding of a topic, concept maps on the topic Solar System constructed by students in two classes that had received the same treatment were analyzed. Both classes participated in inquiry lessons taught by the science methods instructor and then taught the same lessons to elementary school children.

The results indicated that the differences in the scores of the pre and post maps between the two classes was negligible (See Table 2). In addition, concept maps on two different topics, Electricity and the Solar System, constructed by the same students were compared. This analysis also indicated that the same type of intervention resulted in similar improvement in students' understanding of the topics. Therefore, it can be inferred that the same treatment results in approximately the same change in the accuracy and complexity of students' concept maps.

2. Is it more effective for science methods students to work with a partner or alone when constructing concept maps?

I had questioned whether the increased opportunity to interact with a fellow student about relationships among concepts would be more helpful for science methods students' learning about a topic than working individually to construct their concept maps. Situations were set up in which students in one class worked in pairs to construct a concept map while students in another class worked individually. Both classes were taught inquiry lessons by the instructor and then taught the same lessons to children.

The results, although far from significant, indicated that the understanding of students working individually on their maps improved more than the understanding of students working with a partner.

3. Does receiving feedback on their concept maps improve students' understanding of the topic?

Science methods students in one class received feedback about their concept maps of the topic Insects, while students in another class did not. The concept maps of both classes were evaluated using the criteria given in Table 1. The concept maps of the students in the class receiving feedback were returned to the students. These students were shown a sample concept map constructed by the instructor. Attention was drawn to misconceptions that had commonly occurred on students' maps and the relationships among the concepts was explained. After the students had the opportunity to interact with each other and with the instructor about their maps, the concept maps were collected. Both the feedback and the non-feedback classes experienced inquiry lessons and then taught the lessons to elementary children. Six weeks later, the students in both classes again constructed concept maps on the topic Insects.

The results indicated that students receiving the feedback did significantly better than students not receiving feedback (See Table 2).

4. Is developing a unit on a science topic as effective in helping students understand a topic as being taught an inquiry lesson and teaching the same lesson to children?

Science methods students in one class were provided different situations to help them learn about two topics. In the case of one topic, they participated in inquiry activities and then taught the same lesson to elementary school children. For the other topic, they were given the following assignments that required them to learn about that topic:

> Outline the topic, specify a rationale and objective for teaching a unit on the topic. Construct a test to evaluate children's learning of topic. Write lesson plans for several different types of activities to teach the topic to elementary school children and organize the lessons into a sequence to form an instructional unit.

The results indicated that the post concept maps for the topics about which the methods students experienced and later taught inquiry lessons were significantly better than the post concept maps for the topics on which an instructional unit had been developed (See Table 2).

Conclusions

The implications of this study for teaching students with weak science backgrounds enrolled in a methods of teaching elementary science course are:

1. Concept mapping can be used to detect the effects of different interventions on methods students' understanding of science topics.
2. Students received more cognitive benefit from working individually on their maps than from working with a partner.
3. Students were helped by being made aware of my evaluation of the accuracy of their maps and on having their attention brought to focus on misconceptions that had appeared on many of their maps.
4. Experiencing an inquiry activity and then teaching the same lesson to children was much more effective in increasing the quality of connections on concept maps than was developing an instructional unit on a topic.

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Table 1

Criteria Used When Evaluating Concept Maps

	Points
Number of concepts used	2.0
Number of levels on map	2.0
Connecting lines:	
Drawn	0.5
Labeled	0.5
Valid	4.0
Cross links drawn and labeled	1.0
TOTAL	10.0

Table 2

Results of Analysis of Co-Variance of

Pre and Post Scores on Concept Maps

Teaching Strategy	Topic	Number of Students	Mean Score			Equality of Adjusted Means	
			Pre	Post	Adjusted	F-Value	Probabilit
Different students experiencing the same intervention	Solar System	20	5.9825	7.0850	7.5672		
		10	8.2000	8.5500	7.5856	0.0017	0.9677
The same students experiencing the same intervention	Solar System vs Electricity	20	5.9825	7.0850	7.4205		
		20	7.2825	7.7875	7.4520	0.0118	0.9142
Constructing concept maps alone or with a partner	Insects	18	6.5000	6.9056	7.2017		
		18	7.3361	7.2389	6.9428	0.8229	0.3709
Receiving feedback or not	Insects	10	7.1100	8.2900	7.9883		
		18	6.5000	6.9056	7.0732	7.3654	0.0119
Teaching children or developing a unit	Insects vs Unit Topics	10	7.1100	8.2900	8.6498		
			8.1250	7.3500	6.9902	17.6922	0.0006

SOME METHODS FOR EVALUATING THE MEANING OF CONCEPT NAMES

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INTRODUCTION

The following paper deals with methods of concept mapping. It coincides to a certain extent with research activities done here in Ithaca by J. NOVAK (1981).

I would like to describe experiences with some methods for evaluating the meaning of words used in science as names for concepts. Undoubtedly, the learning of concepts is substantially influenced by the everyday meaning of words like work, force, power and energy which are used as names for concepts in science. Becoming familiar with the meaning of such concept names before and after instruction, therefore, provides important information for lesson planning and evaluation.

My main concern in the following sections is to provide some insight into the characteristics of the presented methods. Findings about the meaning of the concepts energy, work, power and force are of less interest here. Another paper at this conference (Duit, 1983a) will deal in some more detail with findings about the energy concept.

More comprehensive overviews of my studies in this field can be found elsewhere (see Duit, 1982, 1983b).

DESCRIPTION OF THE METHODS

A questionnaire is imployed in my studies in order to investigate some aspects of meaning. Four tasks are used.

(1) Associations

The words used in science as names for concepts (e.g. energy, work, power, force) are written on the blackboard one after the other. Every 30 seconds a new word follows.

The students are asked to write down the words which come to their minds when they are confronted with the given word. The responses of the students are categorized according to a scheme of categories presented later.

The association method has been used frequently for purposes of science instruction research. There is one group of researchers which predominantly uses associations to detect relationships between content structure and cognitive structure (e.g. Johnson, 1964, 1967; Johnson, Curran, Cox, 1971; Shavelson, 1974, 1975; Preece, 1976a, 1976b, 1977). Even though stimulus words from science are used (e.g. terms from classical mechanics such as force, power, time, acceleration) the main interest is in psychology. The analysis of associations with stimulus words is mainly oriented to revealing structures among the stimulus words. Sometimes only the amount of associations given to each of the stimulus words is taken into consideration. Generally categorizing associations is simple.

There is another way of using association tests for purposes of science instruction research (see, e.g. Jung, 1981 , 1982; Schaefer, 1976, 1979, 1980; Cochaud, Thompson, 1980). The main interest of the mentioned researchers lies in finding out something about the meaning of concept names within the context of students' knowledge of science concepts. Their methods for analysing and interpreting associations are

fundamentally different from those of the group of researchers mentioned first. Analysis is mainly qualitative. Furthermore, analysis is content-oriented. Rather complicated systems of evaluation categories are used to classify the associations.
My research work concerning association is among the latter group.

Although I think that association tests provide researchers, teachers and curriculum developers with information of some significance for science instruction, limitations of the method should not be overlooked. There is an ongoing discussion about these problems (see, for instance, some papers from a conference on "Cognitive Development" in Leeds; Archenhold et al., 1980). Some of the problems are the following: if a student writes down a word (associates) we don't know why he is doing this, i.e. we don't know anything about links to the stimulus word. Furthermore, we don't know anything about the meaning the student relates with the word at the moment of association (Stewart, 1979). If a student writes down "force" we don't know whether the physics or the everyday meaning is meant. To overcome these difficulties, Gunston (1980) proposes asking for a sentence containing the associated word and the stimulus word.
Another aspect has to be taken into consideration. Association tests as used in my study provide researchers and teachers with a gross insight of meanings that a group of students has. But the information gained for individuals is negligent (see Jung, 1982).

One of the main problems in using association tests for measuring the meaning of concept names is finding a scheme of categories which are of significance with regard to the aims of research. I want to compare the meaning of different concepts. Therefore, a scheme of general categories valid for all concepts is necessary. The starting point for this scheme of categories as presented in fig. 1 was the distinction between "things", "processes", "qualities" and "relations" which is of significance in philosophy as a basic system of general categories. During the development of the scheme of categories modifications of the general system were necessary.

1. THINGS
    - human beings / animals / other things of nature
    - technical appliances (household tools / motors, machines / battery, dynamo / vehicles)
    - industrial plants or factories (e.g. power plants)
    - equipment in physics instruction
2. PROCESSES
    - activities (physical, mental activities)
    - other processes (e.g. "a bulb glows")
3. QUALITIES (of things or processes)
    - (e.g. strength, fluid, hot)
4. PHENOMENA
    - light, heat and others
5. WORDS (CONCEPTS) FROM THE FOLLOWING AREAS:
    - school (e.g. examination, homework)
    - working world, society (e.g. laborer, job, money)
    - emotions (e.g. stress)
    - household, leisure time, sports
6. PHYSICAL CONCEPTS
    - units / formula / terms
    - energy / work / force / power and connections with these concepts
    - specific categories for the single concepts

Fig. 1: Categories for the association test

Category 6 (physical concepts), for instance, was included because I was interested in the names of physical concepts (terms) which come to the minds of the students when confronted with a word used as a name for a concept in physics. Of course, there is a fundamental difficulty in connection with this category. If a student associates "force" with "energy" we can't be shure that the physical meaning of force has come to his mind. It may well be that the everyday meaning is meant.

There are some other "weaknesses" of the scheme of categories as presented in fig. 1. Further considerations in finding a more satisfactory scheme are necessary. But the results gained with this instrument at least offer some insight in the meaning of different concepts which are of significance for planning and evaluating science instruction.

All words associated by the students are categorized. The succession of the words is not regarded.

Very detailed evaluation directions explain the usage of the categories. They provide the scorer with enough information to gain a quite sufficient inter-scorer-reliability (about 90% of all associations in my study are put into the same category by two scorers).

(2) Definitions

The students are asked to write down a definition (or a description) of the concept name. Schaefer (1980) is of the opinion that the definitions reveal some aspects of logical thinking in connection with a concept. But it can be questioned whether this is indeed so. Definitions seem to reveal more about the ability of students to memorize and indicate associative thinking rather than provide information about logical thinking.

Other schemes of evaluation categories are used here. They are oriented to basic aspects of the physical concepts. Therefore, different schemes are used for the different concepts. Fig. 2 presents the scheme used for energy. One may note that an aspect of energy, namely degradation, is missing from among the categories in fig. 2. It was dropped because it was seldom mentioned in the trial runs.

1. Mentioned Concepts
   - work (ability to do work, stored work, energy conversion is work)
   - force (energy gives force / force gives energy / force is energy)
   - power (energy gives power / power gives energy / energy is power)
   - current, electricity
2. Formula (e.g. formula for an energy form / $E = mc^2$)
3. Energy is needed for...
   - globally (for all purposes)
   - living beings
   - technical appliances
   - activities (physical)
   - light, heat
   - others
4. Energy is contained in ...
   - fuels (nuclear too)
   - things in motion, things which are stretched, lifted
   - food
   - sun, wind
   - power plants
5. Energy conversion, energy transfer
6. Energy conservation

Fig. 2: Categories for task 2: definitions for energy

(3) Examples

The ability to give examples is currently seen as an important indicator for concept learning (see e.g. Gagne, 1969; Klausmeier et al., 1974). Gilbert, Osborne (1980) have based an interview method to detect the meaning of a concept on a number of examples for this concept (the IAI-method; Interview about Instances). In my study, examples for concepts are meant to support the information gained through associations and definitions. Whereas the latter throw light upon more general and abstract aspects, examples are oriented to a greater extent to situations, processes and activities. The same scheme of categories used for associations is employed here too (see fig. 1).

(4) Application

Application is undoubtedly a major aspect in concept learning. The application in task (4) is rather simple. The students are asked to make use of the concept names energy, work, power and force when describing the simple process presented in fig. 3.[1]

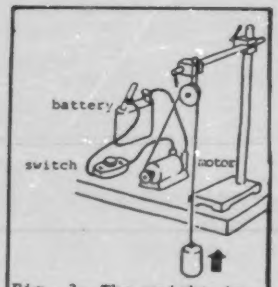

Fig. 3: The weight is lifted when the switch is closed (task 4)

With regard to methods of mapping cognitive structure the way in which the students' answers to task (4) are categorized seem to be of interest. The main idea can be seen in fig. 11. The relations between the concept names as well as between the concept names and parts of the apparatus are portrayed in a matrix like diagram.

SOME EXPERIENCES WITH THE PRESENTED METHODS

In the following section I would like to deal with some experiences gained by means of the methods described (task 1 to 4). As mentioned already my main concern is to illustrate the characteristics of these methods. Findings concerning the concepts energy, work, force and power are of less interest here.

It is important to note that these findings refer to the meaning of the German words for energy, work, force and power. The meaning of these words in the English language certainly differs in some respects.

(1) Associations

All associations given by the students are regarded. If one word is written several times by a student it is regarded only one time.

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[1] In order to get more information about the ability of students to apply concepts, further tasks would have to be added. My questionnaire contained further tasks in connection with the energy concept. They are not payed any attention in this paper (see Duit, 1982, 1983a).

The list of the most frequent associations provides a first insight into the "associative framework". Fig. 4 presents the most frequent associations with "energy" (Energie) given by students before physics instruction. Fig. 5 containes all associations classified according to the categories mentioned in fig. 1. The insight in the meaning of Energy (Energie) for the 147 German students before physics instruction provided by the associations may be summarized as follows. Energie (energy) and Strom (current) are closely related in everyday German language. This aspect is not only revealed by the fact that the most frequent word associated with energy is "Strom" (current, see fig. 4) but also by other findings (gained from tasks 2 and 3, see fig. 8 and 9). Furthermore energy is associated with sources of energy (e.g. fuels like gasoline or the sun), with consumers of energy (e.g. technical appliances), with the importance of energy for society and with

Associated word (English translation in brackets)	percentage of students who mentioned this word
Strom (current)	44
Öl (oil)	18
Energie sparen (saving energy)	14
Licht (light)	14
Kraft (force)	12
Benzin (gasoline)	10
Wasser (water)	10

Fig. 4: Associations with Energie (energy); the most frequent words (147 students/grade 6) without any physics instruction

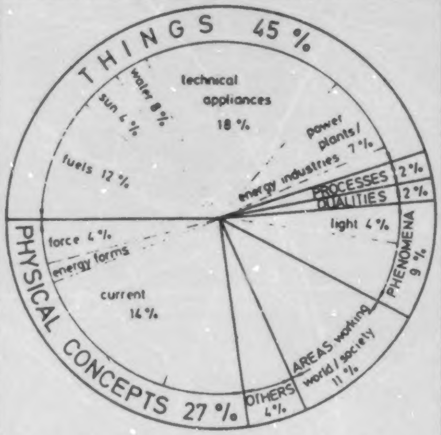


fig. 5: Associations with "energy" (Energie) 147 students/grade 6/without any physics instruction

The percentages are based at all words given by the students.

phenomena like light, heat and motion. Force (Kraft) is among the most frequent words (12% of all students write down this word, equivalent to 4% of all associations given by the 147 students). Other findings are even more in accordance with complaints of teachers that there is a mix-up between energy and force. But although there are undoubtedly such muddles, energy and force by no means have the same meaning. The associations with force (see fig. 6) point out, for instance, that this word is associated predominantly with physical activities, with the word muscle and with strength (the associated animals and human beings are mostly strong, e.g. weightlifter or elephant).

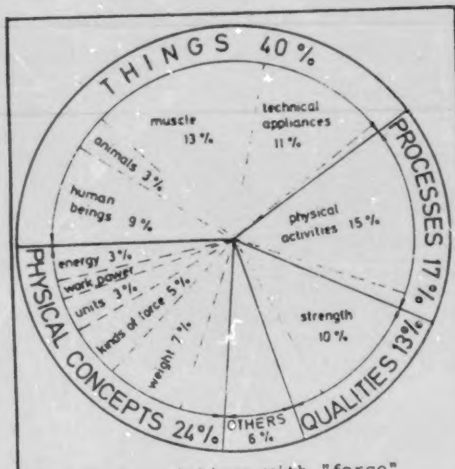


fig. 6: Associations with "force" (Kraft). 147 students / grade 6 / without any physics instruction

With regard to the significance of the employed scheme of categories and my use of association tests in general, it is important to mention that the pie charts for other German language samples (e.g. Swiss students in grades 7 and 10 without any physics instruction) are very similar to those presented in fig. 5 and fig. 6. The method, therefore, seems to reveal some general aspects of the meaning of concept names in colloquial German language.

In my studies students after physics instruction are also asked for associations with words used as names for physical concepts. Fig. 7 presents the results for students after 4 years of physics instruction during which the energy concept was given some attention.

It is not possible simply to compare the charts of fig. 5 and fig. 7. The students without any physics instruction are asked for the meaning of energy in everyday language, the students in grade 10 for the meaning in physics. Taking this difference into consideration one may give the following interpretation. The diagrams are very similar. The main difference is a larger number of energy forms and other connections with energy in grade 10. Besides this, the general structures are the same in both charts. It seems that physics instruction has basicly not changed the meaning of energy the students bring into instruction. This interpretation is supported by several other findings (see Duit, 1983a, 1983b).

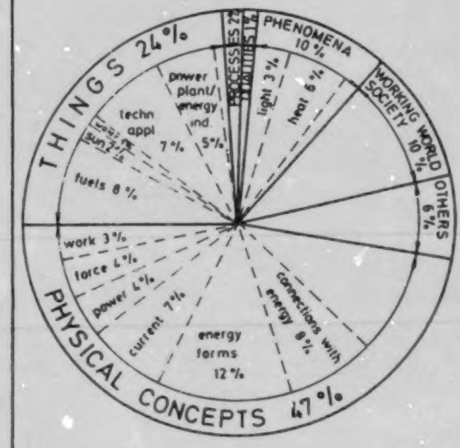


Fig. 7: Associations with "energy" (Energie). 171 students / grade 10 / after physics instruction in grades 7 to 10.

(2) Definitions

The definitions support the insight into the meaning provided by associations. Fig. 8 presents some results concerning energy. The concept names "force" and "current" (or electricity) are mentioned most frequently among students without physics instruction. Students after physics instruction prefer work but also mention force and current to a remarkable extent. With regard to the aims of energy instruction with respect to

1. Mentioned concepts	German schools grade 6	grade 10
WORK	3	42
- energy necessary for work	1	21
- ability to do work	-	4
- energy is stored work	-	10
FORCE	18	14
POWER	1	7
CURRENT / ELECTRICITY	21	12
5./6. Energy conversion and energy conservation		
- energy forms	3	12
- energy conversion	-	10
- energy transfer	1	1
- energy conservation	-	11

Fig. 8: Definitions for energy (The figures give percentages. Note, that only some of the evaluation categories contained in fig. 2 are regarded here.) 147 students / grade 6 // 171 students / grade 10.

grade 10 students it is discouraging that only a rather small fraction of students mentions the aspects of energy conversion, transfer and conservation.

(3) Examples

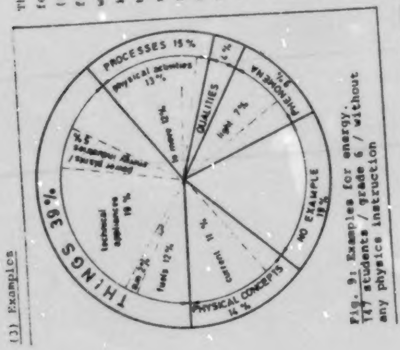


Fig. 9: Examples for energy. 147 students / grade 6 / without any physics instruction

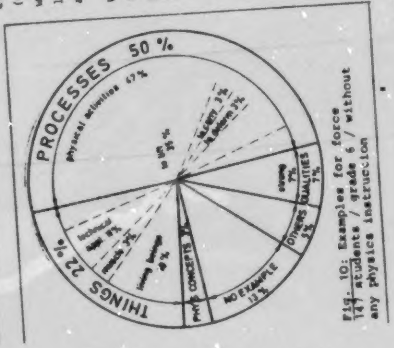
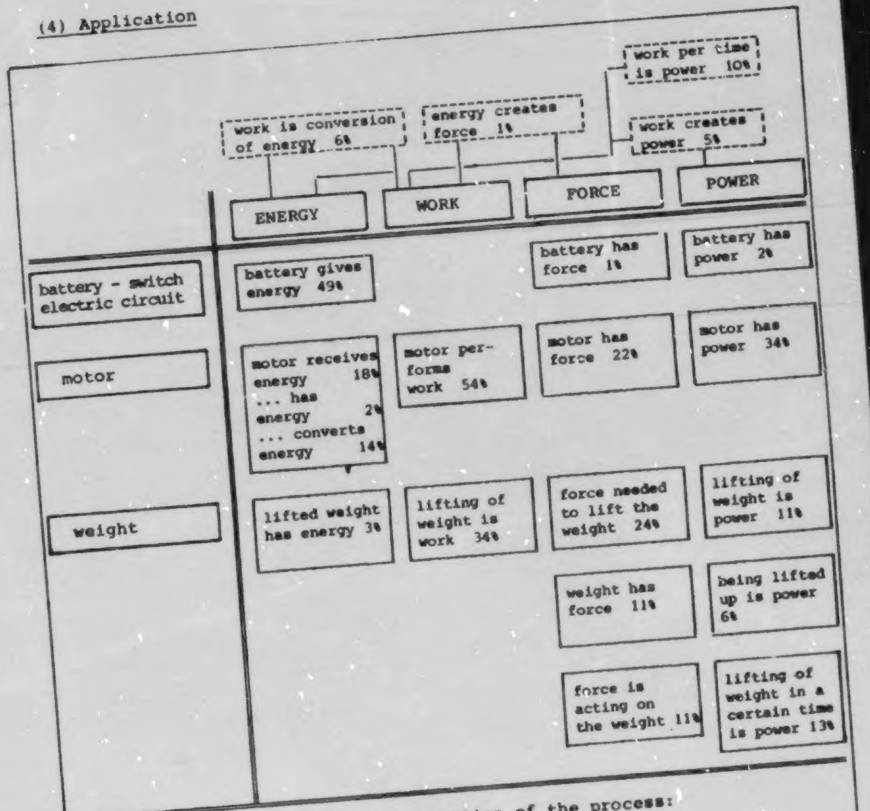


Fig. 10: Examples for force 147 students / grade 6 / without any physics instruction

The examples given for energy and force (see fig. 9 and fig. 10) by students without physics instruction support the findings presented so far. Force seems to be associated predominantly with physical activities and strength. The "associative framework" of energy seems to contain several sources and uses of energy in different domains, electric current (electricity) as well as phenomena like heat, light and motion.

With regard to the significance of the method used here, it is important to mention that the diagrams for the German language samples of students without any physics instruction are very similar.

(4) Application



work is conversion of energy 6%

energy creates force 1%

work per time is power 10%

work creates power 5%

	ENERGY	WORK	FORCE	POWER
battery - switch electric circuit	battery gives energy 49%		battery has force 1%	battery has power 2%
motor	motor receives energy 18% ... has energy 2% ... converts energy 14%	motor performs work 54%	motor has force 22%	motor has power 34%
weight	lifted weight has energy 3%	lifting of weight is work 34%	force needed to lift the weight 24% weight has force 11% force is acting on the weight 11%	lifting of weight is power 11% being lifted up is power 6% lifting of weight in a certain time is power 13%

Fig. 11: Results for task 4 (Description of the process: a motor connected to a battery lifts a weight). 171 students / grade 10 / after physics instruction in grades 7 to 10.
The percentages of students with no answer are: energy (12%), work (17%), force (19%), power (17%).

Fig. 11 presents results from the description of a simple process (see fig. 3). Please notice that the percentages refer to students at the end of grade 10 (after four years of physics instruction during which energy was tought at some detail).

The matrix-like diagram structures the responses of the students. It portrays relations between the concept names and parts of the used apparatus. Relations between concept names are contained in the boxes indicated by broken lines. The diagram, therefore, may be taken as a kind of concept map portraying the use of concept names when describing a process.

Energy is used predominantly within the following scheme: the battery gives energy, the motor receives energy.
Work, force and power seem to be related predominantly to the motor and the weight.
The boxes in fig. 11 reveal some uncertainty on the part of the students to refer to the physics meaning when employing the concept names to describe the process. The statement "battery has force", for instance, does not reflect the use of the meaning of force in physics. This is true also for the statement "motor has force". In this statement force is seen as a property of the motor. Such an idea is in contradiction with the notion of force in physics which refers to interaction between two systems.
In general, the findings presented in fig.11 point out uncertainty on the part of the students when using the concept names in a manner one would have expected considering the physics instruction given to the students.

SUMMARY

The paper deals with some methods for evaluating the meaning of concept names (associations, definitions, examples, applications). Theoretical considerations concerning the methods are contained in a preceding section. They shall not be reiterated here. Only a summary of experiences with the methods is given.

(1) The schemes of categories used for the evaluation of students' responses seem to reveal aspects of some significance for science instruction although there are some problems with these schemes (see above).

(2) The methods measure significant aspects of meaning. This may be inferred on the basis of the fact that the diagrams and charts obtained in comparable contexts of language and culture (students without any physics instruction in Germany and Switzerland) are very similar. This concurrence of structure revealed by the scheme of categories for associations (see fig. 1), for instance, is remarkable especially because very different words are associated in the different samples. Similar findings with regard to association tests are reported by Schaefer (1980).

(3) The findings gained through the different methods support one another. Conclusions concerning the meaning of concept names always should be based on results from all methods employed.

(4) The methods do not give much information about the ability of the students to make use of the concepts. Information about the "associative framework" predominate. This is also true for results gained through definitions. They, too, mainly, offer an insight into the surface structure of meaning.
Nevertheless, the insight gained into such surface structures is useful when planning science instruction.

(5) Although the responses of individual students provide information about the meaning this student holds, the methods are mainly suited to investigate the meaning among a group of students.

(6) The methods are in principle, easy to handle. They can also be used, for instance, by a teacher to get insight into the meaning of concept names when starting a new topic.
This is so because a teacher can choose his evaluation categories more intuitively than researchers can.
If criteria of scientific research have to be complied with, the scoring of the associations, definitions, examples and descriptions is a rather difficult task. The manifold aspects

require detailed evaluation directions. Much effort is needed, too, to score the students' answers according to these directions. As was already mentioned, a quite satisfactory inter-scorer-reliability is attainable when using the directions. In random tests two scorers put about 90 % of all answers into the same category.

(7) The methods presented here are qualitative methods. Comparisons of diagrams or charts for different concepts are based on differences in characteristic structures. No index of similarity (or the like) has been used so far.

I would like to conclude this paper with some summarizing comments on advantages and disadvantages of the methods.
I think that they reveal important aspects of meanings students hold. The information gained by employing my tasks considerably aid lesson planning and evaluation for teachers and curriculum developers. They offer, for instance, significant insight in aspects of preinstructional conceptions and notions.
But one has to be aware that there are considerable limitations to the methods. Whereas problems of scoring reliability may be solved sufficiently, problems of validity still remain. One of the most difficult problem is to categorize the answers of the students, appropriately. This is true especially for associations and examples. Therefore, further considerations are necessary in order to overcome some of the mentioned limitations. I hope to have presented some arguments proving to be promising for future research.

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Ten Rules of Thumb: Information Processing Interpretations of Error Research in Learning

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Are student mistakes ever valuable? Yes indeed, according to many educational researchers and teachers. Errors provide valuable clues to students' thought processes, thus helping teachers to design more effective instruction and provide more specific remediation.

When students come into the classroom, their minds are not blank slates. They are full of ideas, concepts, and ways of thinking acquired over the students' lifetimes. As we learn, we create internal mental representations (images, models, words) of some aspects of the world around us. According to cognitive psychologists, our mental models are typically incomplete, imprecise, and inaccurate. In computer jargon, mental programs tend to be full of bugs. Good teaching, therefore, requires more than clear, concise, and enthusiastic presentation of new material. It is also important for teachers to help students debug what they already know.

According to Kelley (1963), learning occurs through an infinite series of successive approximations. With each successive level of understanding, some of the previously-held relationships or concepts may be modified, sharpened, or discarded, and some new ones added. Learning is thus an active, constructive process which may involve such steps as reorganizing ideas, perceiving new relationships, or developing new skills. In order for students to add a new idea to their mental framework in more than a superficial (rote memorization) way, they must establish meaningful connections between that new idea and what they already know.

Given this framework, student errors become (to the extent possible) objects of interest rather than occasions for punishment. They reveal features of students' mental models that need further refinement. Most student errors are systematic and persistent, reflecting particular bugs or misconceptions in the students' mental programs. Teachers can learn a great deal from their students' mistakes.

On the other hand, while errors provide valuable insights into underlying thought processes and can be useful devices both in learning and in discovering new ways of seeing, they are not particularly desirable when good performance is expected. Our goal as teachers is usually to minimize the number of erroneous ideas a student acquires while learning something new, and to maximize the number of errors which can be identified and pruned out of what the student already knows. To achieve this, we must monitor student errors regularly and systematically debug both (1) our instruction and (2) students' mental models.

Practically speaking, what does this mean about how we organize our classrooms? Although specific practices will vary with the subject matter, ten general rules of thumb are summarized below.

1. Create a safe environment. Let students know that learning is hard work and that everyone (including teachers and experts in the field) makes mistakes when they are learning. Provide many non-punitive opportunities for students to make mistakes and reveal their misconceptions. This may be done in a variety of ways, as with guided group discussion (see especially Minstrell, 1982), homework problems, or quizzes. Avoid grading, especially normative grading, during these times because of its inherently punishing nature for many students. Frequent quizzing with mastery grading (allowing repeated tries until the students successfully eliminate their bugs) can be effective. Never ridicule students or put their ideas down. Treat every naive theory with interest and respect.

2. Present problems which help expose common student errors. So long as our concept seems to us to be a satisfactory representation of the external world, we have little incentive to modify it or to acquire an alternative way of thinking. Once we become aware of the shortcomings of our concept, as, for example, by realizing that it leads to erroneous predictions or incorrect answers, we begin to recognize the need for refining our idea or acquiring a better one. Good study or discussion problems are those which help students recognize certain inadequacies in their present level of understanding, thereby challenging them to discover more satisfactory and powerful ways of thinking.

3. Present an alternative way of thinking and encourage students to test your mental model. Exposing bugs in the students' mental models is valuable but insufficient. It is critically important that the teacher follow up by presenting an alternative mental model, one which works better. Students need time to assimilate the new model, test its predictive validity or functional value, practice with it, and to debug their understanding of it.

4. Help students to make their implicit knowledge explicit. Our conscious thought processes are often influenced by our tacit, subconscious assumptions. As we acquire knowledge of the world through personal experiences, that knowledge may be stored in forms that are not readily accessible to our conscious mental processor or readily described in words. Misconceptions or bugs in our subconscious knowledge can produce systematic errors in conscious performance. Assumptions based on our experience with moving objects in a friction-filled world, for example, apparently make it difficult for us to imagine how objects would move in a frictionless environment (Clement, 1982). Making implicit ideas explicit can be a difficult but valuable exercise.

5. Include many concrete, familiar, and relevant examples in your instruction. This has at least two major advantages. In the first place, it minimizes the information processing load. When a new idea is presented in an unfamiliar context, the student has to devote a lot of mental energy to trying to comprehend and learn about the context, and may lose sight of the main idea altogether. In contrast, when the idea is described in a familiar setting, even if it involves approximation or analogy, the student can focus on the idea itself and its implications in the familiar environment. In the second place, it is becoming increasingly clear that meaningful learning (as noted earlier) requires establishing meaningful connections between what is already known and what is to be understood. When new concepts are presented in abstract, isolated form, many students

only recourse is to employ rote memorization. Ideas learned by rote memorization are rapidly lost unless used regularly, whereas "deep level" understanding tends to be resistant to forgetting.

6. Whenever possible, present new information in the form of a story. Human beings are natural story tellers and listeners. It seems that over many centuries we have evolved a variety of general mental structures for listening to, accomodating, comprehending, and telling stories. A story, since it has a beginning, a middle, and an ending, has far greater coherence than lists of individual facts. The story format therefore facilitates recognition of relationships and recall. Hence the parables of Jesus and other prophets.

7. Emphasize the value of redundancy and checking. We can be more certain of an answer when we can derive it in at least two different ways. Common sense evaluation and estimation are critically important habits, and various instructional methods need to be devised to assure that students acquire them. Students should learn to appreciate the value of routinely monitoring their performance and debugging their mental programs. One "trick", for example, when learning addition, is to add in both directions and then check the sums of the sums. For example,

$$\begin{array}{r} 5\ 4 = 9 \\ +\ 2\ 3 = 5 \\ \hline 7\ 7 = 14 \end{array}$$

8. Promote conscious examination of mental mechanisms. For example, many problems can be represented in several different ways (such as verbally and visually). It is useful to find out how students think about a problem spontaneously, to help them discover alternative ways of thinking about the problem, and to give them practice in moving back and forth between representational systems. A strong word association can induce a student to pick an incorrect answer on a multiple choice question (Fisher, 1985). It is a useful strategy, therefore, for students to cover up the answer choices until they have thought about the question and decided upon a general answer (when this is possible), and then select the particular answer choice that best agrees with the answer they have already decided upon.

9. Provide opportunities for students to practice, practice, practice, with frequent feedback on and discussion of their performance. It has been estimated that it takes about 50,000 hours to become an expert in doing anything. According to Anderson (1982), skills are acquired in two stages. First we learn about doing something (declarative knowledge), then we learn to actually perform the thing (procedural knowledge). We don't really become good at performing until we (a) have "chunked" many individual facts together, (b) are able to "run" the mental procedures automatically and subconsciously, and (c) and have acquired a broad and well-organized base of knowledge about the skill. Time-on-task is a critical factor. As a football player once said, "We practice all week long so we can improvise on Saturday." It is also important to have accurately identified all the subtasks involved in successful performance, as illustrated by Heller and Reif (1984).

10. Recognize that most or all cognitive errors have multiple causes. When we experience a "slip of the tongue", for example, we don't insert any randomly generated word from our vocabulary into a sentence. The word we say may sound like the word we intended to say, may have similar semantic properties, may reflect something we were thinking about but didn't intend to say, and so on. It follows, therefore, that multiple strategies are necessary for good error management. Any one strategy listed above is insufficient in itself.

In summary, errors provide valuable insights into students' ways of thinking. Good instruction involves not only the presentation of new material, but also systematic means for debugging knowledge as it is acquired and once it is learned. Mistakes are a natural (not a shameful) part of the learning process. Effective instruction encourages students to discover and reveal their errors during learning, and provides concrete, detailed, and more successful ways of thinking. Teachers and students become allies in the debugging process.

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Enhancement and assessment of the Reliability of Instruments for the Measurement of Conceptual Frameworks

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This paper deals with the reliability of instruments for the measurement of conceptual frameworks. It first describes the nature of reliability and some of its threatening factors inherent in the widely used clinical interviews. Then it proposes principles for the enhancement of the reliability of both clinical interviews and written problem solving tests and ways to assess this relaibility. Finally it describes an interview and problem solving test schedules that implement these pronciples.

1. Reliability of Measurement Instruments

The reliability of a measurement instrument is an index for its dependability or consistency on repeated administrations. A variety of conventional psychometric methods exists for the assessment of reliability of tests. These measures use the scores on individual items or on subtests. They are strongly contingent on the features of the measured phenomenon, the instrument, and the administration procedures (e.g. Anastasi, 1982).

There are numerous reasons why these methods are inapplicable to the nonstandardized interviews, among which are the following: (1) The study of conceptual frameworks and misconceptions is relatively new. Its instrumentation is in its early developmental phases and their standardization is premature. (2) When problem solving tests are used to identify misconceptions, it is not the conventional measures of correctness that is considered, but rather the nature and type of the errors. (3) The test-retest method cannot be used since the reactivity of the interview prevents its administration twice within either a short or a long time interval. (In the first case remembering previous performance, transfer and learning are highly probable, and in the second, real changes in the conceptual framework might occur.) (4) It is impossible to employ the split-half method or other internal consistency methods since it is difficult to identify equivalent parts of the interview. (5) It is impossible to use inter-rater agreement methods since each interviewer creates her/his data. Hence, this method requires to interview the student twice in a short time period, by either one or two interviewers. (6) It is difficult to embody consistency checks in the interview by repeating certain questions. This practice is tentamount to administrating the interview twice.

To analyse the reliability of instruments for the measurement of conceptual frameworks, which are mainly clinical interviews, I want to distinguish three parts of the measurement process: The *task* that the student performs, the *record* of this performance, and the *inference* of the conceptual frameworks from the analysis of these records. Hence, the reliability of the inferred conceptual frameworks depends on the reliabilities of its preceding parts, with the reliability of the task being a *sine qua non* for this reliability. The latter can be enhanced by increasing the reliability of the first two parts or that of the analysis and inference. My proposals refer only to the reliability of the task which is used to elicit student's responses. I do not deal with the methods for protocol analysis by which the conceptual frameworks are inferred from the performance.

The reliability of the task can be assessed both directly and indirectly. The *direct* approach assesses the consistency of *microperformance* by comparing the performance on certain parts of the task. The *indirect* approach assesses the consistency of *macroperformance* by comparing the conceptual frameworks that were inferred from certain parts of the task.

2. The Nature of Conceptual Frameworks and Misconceptions

A conceptual framework (often referred to as a schema or knowledge structure) is a system of interrelated concepts, propositions and procedures. It is designed to account for a knowledge domain, for its parts and aspects, or for the performance on a task within this domain. This neutral (non-evaluative) definition does not judge a conceptual framework as correct or incorrect as long as it apparently accounts for a certain phenomenon. This account is considered inadequate if it does not fully explain what it is designed to explain. It is considered incorrect when it is incompatible with the current scientific explanation. Hence, for a conceptual framework to be incorrect or improper it is sufficient that either (1) at least one of the its concepts or propositions (rules) is incomplete, partial, or has an incorrect or improper meaning, or (2) it is applied either incorrectly or in an improper context.

A misconception is an evaluative term that refers to an improper or incorrect conceptual framework. It indicates a mismatch between a conceptual framework held by a person (or a group of persons) and the "correct" one.

3. Problems Associated with the Reliability of Clinical Interviews

Conceptual frameworks are measured mainly by clinical interviews (e.g., Driver, 1973; Rowell, 1978; Pines, 1977; Champagne Klopfer, DeSena, and Squires, 1981). Their reliability can be jeopardized by many factors that were discussed by Piaget (1929), Nussbaum and Novak (1976), and Posner and Gertzog (1982). However, additional factors exert their influence in these settings. Of these I explicate several that seem to be related to reliability.

Factors relating to the interview setting

The following factors in the interview setting may have strong impact on student's responses and jeopardize the task reliability.

1. Incongruence with previous experience. Interviews frequently deal with qualitative (nonmetric) aspects of conceptual frameworks. In this respect they are at odds with the quantitative treatment of these situations that is the common practice in high school.

2. Reactivity. Interviews can be very reactive, i.e., they might change the measured conceptual framework during the measurement process. This reactivity is caused by:

(i) Unfamiliarity with the situation and/or its aspects. Such unfamiliar situations are often chosen to observe the operation and adaptation of the established conceptual frameworks to new settings.

(ii) Learning and transfer. These might occur especially when the probes and tasks are arranged in ascending order of complexity or difficulty, when the same or similar problems are used in one study, and when feedback is provided to the student. (e.g., Novak's (Novak et al., 1981) use of the Concept Mapping task as a learning instrument.)

(iii) Threatening settings. The student might respond to the perceived interviewer's expectations and act under the threat of potential failure.

(iv) Presence of contradictory conceptions. The interview, if successful, exposes discrepancies between "physics", or an official conception, and the real world as it is perceived and interpreted by the student. Such experiences might either make the student too anxious or cause her/him to change specific concepts or parts of the conceptual frameworks.

3. Confounding of problem solving skills and conceptual frameworks. It is very difficult to identify and separate problem solving skills from their underlying conceptual frameworks and knowledge structures.

Factors related to the nature of conceptual frameworks

Certain features of conceptual frameworks can easily be confused and lead to incorrect inferences.

1. The aspects and dimensions of conceptual frameworks are difficult to identify and distinguish.

2. Conceptual frameworks have different degrees of generality, comprehensiveness, prevalence, stability, consistency, and susceptibility to change. They also differ in the conditions under which these changes occur and the relative ease of these changes.

3. The distinction between errors and misconceptions is very subtle, and one may be mistaken for the other.

4. Conceptual frameworks are often based on, and use analogues from other domains which if not identified might mislead the interviewer and/or the analyst.

Factors related to student characteristics

Student characteristics have an impact on the task performance and might therefore endanger the reliability of the task. Some individual differences are the following:

1. The ability to express thoughts, and to be reflective on one's thinking, i.e., to explicate an underlying conception and specify its assumptions, and to explain how existing conceptual and procedural knowledge are applied.

2. The ability to perceive and relate to elements (concepts, variables, and propositions) in situations and problems.

3. The amount of filteirng of the flux of the incoming information by the conceptual frameworks.

4. The ability to construct representations for the task that enable the consideration of the interviewer's proposals.

5. The ability to retreive specific information pertaining to the task.

6. The ability to memorize and remember arguments raised during the interview.

7. The speed of processing the information presented in the interview.

8. The ability to compare propositions regarding the situation and the student's arguments.

4. Means to Enhance the Reliability of Conceptual Frameworks Instruments

The two major difficulties described so far are (1) the inapplicability to interviews of the conventional psychometric methods for the assessment of interview reliability, and (2) the threats to this reliability from three kinds of factors. In view of the difficulties in assessing the reliability of conceptual frameworks, which is not an objective by itself, the following proposals aim to enhance the task reliability. They estimate reliability by the both the direct and approaches, i.e., by comparing certain elements and the conceptual frameworks that were inferred from certain parts of the task. These proposals apply to clinical interviews in which the student is asked open-ended questions about the qualitative and semi-quantitative aspects of a specific situation, and to interviews and written tests in which the student solves problems quantitatively.

A. The Clinical Interview

Principles for the construction of interviews

The following principles for the construction of interviews attempt to rule out some of the threats posed by the previously described factors.

a. Present probes that are not hypothesis-biased.

b. Try to standardize the interview administration by carefully structuring its schedule. Of particular importance is to plan the interviewer's references to student's concepts and arguments. The interviewer should be thoroughly trained in the use of this schedule.

c. In the interview use situations that differ in their familiarity, their similarity in statement, and in their structure. Introduce several tasks in every situation.

d. In each situation present the student with conflicting conceptual frameworks, including the correct one. Do it in a non-authoritative manner, preferably as "other student's answers".

e. Include in the conflicting conceptual frameworks both relevant and irrelevant elements which are intuitively appealing and/or typical to the studied population.

f. Ask the student to explain the meaning of specific terms and propositions that s/he mentions. Point at inconsistencies or incompatibility of her/his concepts and arguments and ask for their explanation.

g. Maintain a close correspondence between the generality of the studied conceptual framework and that of the employed situations and domains.

The interview schedule

Several of the above listed principles were implemented in a clinical interview schedule that was employed in 1982 at LRDC, University of Pittsburgh. It was designed to measure conceptual changes following a science course for talented students of about 12 years of age. The project was run by Audrey Champagne and Leo Klopfer. The interview is neutral i.e., it is not obliged to any theory or hypotheses of conceptual change or the student's memory organization (e.g.. network or hierarchical). It includes three major parts and comprises elements from interview schedules employed by Champagne and Klopfer (1980), Gilbert and Osborne (1980), Gorodetsky and Hoz (1980), and Nussbaum and Novak (1976).

i. The Prediction Part: in this part the student is presented with a concrete situation and is asked to make a prediction of a certain event. S/he first makes the prediction orally and draws it on a diagram of the situation that includes only the elements of interest. Then s/he writes down the prediction and explains it orally, pretending the interviewer is a student of her/his age. Finally s/he writes down the explanation. The student is explicitly asked about the source(s) on which the answer was based (such as personal experience or knowledge, common sense, or scientific rules).

2. The Alternative Predictions Part: In this part the student is presented with several conflicting predictions and explanations proposed by "other students". Each of the alternative predictions is accompanied by a diagram of the predicted outcome. Despite their apparent correctness these explanations are incorrect or inadequate, because they are either partial or include incorrect propositions. The student first reads the prediction outloud, observes the drawn prediction and reads the explanation outloud. Then these are concealed from her/him and s/he is assigned four tasks: (a) to recall and to draw the prediction and the explanation without probes, (b) to explain the meaning of certain terms and propositions in this explanation, (c) to judge the similarity of the proposed prediction and explanation and hers/his, and (d) to agree/disagree with the alternative explanation and to explain her/his agreement/disagreement.

The student goes through several such alternative predictions and explanations. Their number depends on the nature of the studied conceptual frameworks and on the precision that the researcher wishes to achieve.

3. The Observation Part: In this part the interviewer demonstrates the actual event and the student observes it. S/he is then asked if s/he was surprised by the observation, and if so--why. S/he is then asked to describe the event orally, to draw it on a schematic diagram, and to write down her/his description. Finally s/he is asked to note discrepancies between her/his prediction and the observed outcome and to explain them orally and in writing.

Enhancement of the Interview Reliability

The reliability of this interview is enhanced by the following features:

(1) The spontaneous oral responses may be based on perceptual and intuitive conceptual frameworks. By writing them down the student has a second opportunity to reason about her/his arguments, and to modify them by referring to deep-rooted conceptual frameworks.

(2) The amount of answers given at random and by romancing (Piaget 1929) is reduced, since the student knows that the answers have to be justified twice and written down.

(3) The student is allowed to make comments and to ask clarification questions before and during the prediction. This practice may discard responses that arise from either incomplete perception or misinterpretation of the elements in the situation.

(4) The student is required, encouraged and helped (i) to elaborate on her/his conceptual frameworks, (ii) to explicate underlying assumptions, and (iii) to describe the ways in which these conceptual frameworks are being applied to the situation. These practices can

decrease the likelihood of only scraping the underlying conceptual frameworks.

(5) The task of evaluating the alternative predictions and explanations might present to the student and require her/him to consider elements that s/he completely ignored, considered irrelevant, or did not mention because s/he was not confident about them.

(6) The recall task makes it clear whether the elements of the alternative predictions and explanations were actually present in the student's memory when s/he deals with others' arguments. The student's awareness of the need to recall these alternatives probably motivates her/him to pay attention to their elements and to try to memorize them. Their presence in memory increases the likelihood that reference to their elements is made consciously and may thus be considered significant rather than accidental.

(7) The evaluation of the alternative predictions and explanations helps to delineate the student's conceptual frameworks and their aspects and dimensions. This may increase the analyzability of the responses.

(8) The systematic reference to various elements and the questioning about them serve to control the following individual differences: the ability to express thoughts, to explicate assumptions, to process and deal effectively with the interviewer's arguments, and the speed of information processing.

(9) The effects of several interview-related factors are reduced because the student is probably less anxious knowing that (i) the emphasis is on evaluating other's rather than her/his explanations, (ii) her/his answers are not matched with the "scientific" explanation but

rather with answers similar to hers/his, (iii) s/he is not the only one who can be confused by this situation, and (iv) apparently correct conceptual frameworks and explanations turn out to be erroneous on a close examination. It should be noted, however, that since the interviewer does not provide feedback on the correctness of the answers the student might grow more anxious and less confident about her/his conceptions.

(10) The analyzability of the responses is enhanced by the drawing of the observation and by its explanation. These constitute an unambiguous record of the student's perception of the demonstration.

(11) The detected and the undetected differences between the observation and the student's prediction, and the explanation of the perceived differences between the two, clarify the precise nature of the observation and its relation to the student's prediction.

Assessment of the Interview Reliability

The assessment of the task reliability is both direct and indirect. It consists of checking the consistency of certain elements and the inferred conceptual frameworks within or between interviews. The within-interview consistency is estimated by first deciding on the elements of interest and independently obtaining the conceptual frameworks for every major part or subparts of the interview. Then these elements and conceptual frameworks are compared. The between-interviews consistency (or stability of conceptual frameworks) is assessed by first dividing the students into two equivalent half-samples, for each of which certain elements are picked up and "group conceptual frameworks" are constructed for every major part or subparts of the interview. These elements and the corresponding group conceptual frameworks are finally compared.

The following means to estimate the interview reliability apply to both types of consistency despite the lack of appropriate ways to construct a representation of a "group concepatal framework" out of the individual ones.

(1) The prevalence of conceptual frameworks is indicated by differences between the oral and written responses within each part of the interview. Such differences also distinguish intuitive from deep-rooted conceptual frameworks.

(2) The relationships among the elements of the student's conceptual frameworks are indicated by the ways in which s/he evaluates the alternative predictions and explanations.

(3) The distinction between misconceptions and errors is indicated by the ways in which the student treats the alternative predictions and explanations.

(4) The generality, consistency, and comprehensiveness of conceptual frameworks and misconceptions can be astimated by (i) the differences between the conceptual frameworks that were inferred in the second and third parts and the baseline conceptual framework obtained from the first part, (ii) the perceptual elements to which the student referred before the interview started, and (iii) the evaluation of the alternative predictions and explanations.

(5) The effects of other factors characteristic of the second and third parts (such as exposure to other conflicting conceptions) can be assessed by comparing the conceptual frameworks obtained in these parts with either those of the baseline or of any other obtained ones.

(6) The stability and extension of conceptual frameworks are indicated by the elements that are added and/or deleted from the conceptual frameworks obtained in the second and third parts, relative to those inferred from their preceding parts.

(7) The prevalence of conceptual frameworks is indicated by the amount of information that they filter. This is measured by the number of elements that (i) are neither recalled nor treated in the second part, and (ii) are distorted, unnoticed, or unexplained in the observation part.

(8) The elements of the situation that were implicitly considered by the student can be revealed by the distortion of the observation, the comparison of the self prediction with the observation, and the detection and explanation of differences between the two. These can be used also to estimate the student's ability to make comparisons.

(9) The amount of learning, transfer, or conceptual change which are produced by either the task or other relevant features (which have to be identified) of its parts can be estimated by (i) the nature and amount of the noted and unnoticed discrepancies between the student' prediction and explanation and the alternative ones, (ii) between the former and the observation, and (iii) by the differences between the conceptual frameworks that were inferred in the various parts of the interview.

(10) The interviewer's consistency can be assessed by comparing the nature and amount of differences between her/his probes in corresponding parts of different interviews.

(11) Additional interesting aspects can be derived from the nature and amount of recall of the alternative predictions and explanations (e.g., Voss, Tyler, and Bisanz, 1982).

B. Problem Solving Tasks

Milka Gorodetsky and myself, at Ben-Gurion University, have developed the following schedules that enhance the relaibility of problem solving tasks. These were administered in interview setting and in paper and pencil problem solving tests for students of 13 to 18 years of age.

Schedule 1: Administering orally a test comprised of two main problems that are identical, except for their numerical values, with a series of easier problems which is introduced between them. These problems deal with fewer aspects of the two main problems.

Schedule 2: Administering a questionnaire which contains two problems that are structurally different despite their apparent similarity of statement.

These schedules were used to study the comparison of pure and metric decimal rational numbers, and the solution of speed problems. They are briefly sketched below.

Schedule 1.

The questionnaire consists of the two following comparison problems each having four parts.

Problem 1: a. Student A has a stick 29.5cm long. Student B has a stick 180mm long. b. Student A argues that his stick is longer, because a cm is longer than a mm. Is he right? Explain. c. Student B argues that his stick is longer, because 180 is more than 29.5. Is he right? Explain. d. Who has the longer stick? Explain.

Problem 2: Identical to problem 1 with numerical values of 142 mm and 16.1 cm, respectively.

The student responds to one part of the problem at a time. The intervening series involves the comparison of several pairs of pure (without metric units) numbers (e.g., decide which number is greater, and explain your answer: 3.8 or 0.36?) and of several pairs of metric numbers (e.g., decide which number is larger and explain your answer: 70 cm or 0.7 m?).

We have found that the intervening series had significantly affected the performance on the second problem (relative to both non-inclusion of the intervening series and the omission of the first problem). These results indicate that the performance on the complex problems may sometimes be unreliable, and that by including the intervening series the reliability of the test was improved.

Schedule 2.

Administering a test that includes two apparently similar problems with different structures. We have used the following speed problems.

Problem 1: Two cars started from city A. They go to city B, and return without delay. The distance between the cities is 120 km. Car 1 goes to city B at the speed of 30 km/h and back at 50 km/h, and Car 2 goes both ways at the speed of 40 km/h. Which car returned first to city A?

Problem 2: Identical to problem 1 with distance magnitude not given.

Students' answers were accompanied by explanations whose analysis yielded a hierarchy of six solution models. These solution models served to infer the underlying conceptual frameworks. The performance on only one of the problems turned out to be very unreliable, since despite the structural difference between the problems, students tended to employ the same incorrect solution models to both. Consideration of the solution models that were used for the two problems yielded more reliable inferences of the underlying conceptual frameworks (Gorodetsky and Hoz, 1983).

Conclusion

In the present state of the research on conceptual frameworks reliability is a rather neglected issue, despite its importance. Every effort must be made to identify the sources of unreliability in the employed instruments, and to propose appropriate safeguards against them. The proposals of this paper constitute a step towards the improvement of the reliability and its assessment in both interview and written tests.

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Informal Conceptions of Probability

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Probability is a particularly slippery concept. The difficulty has not so much to do with the fact that probability is a family of concepts made up of separate yet not quite distinct members; many concepts share this distinction. Nor is the difficulty a result of the concept's conversion by mathematicians and philosophers into a technical term; again, many of our concepts have been born again in scientific garb and caused much less of a stir. What is uniquely troublesome about probability is the territory it stakes out. It attempts to demarcate the amorphous state somewhere between total ignorance and perfect knowledge. And it is trying to keep one's footing in this nowhere land that is particularly disturbing. Like a frictionless surface, it not only trips you up, but keeps you sliding once you're down.

While the nature of the concept continues to be a matter of division and debate among philosophers of probability, it is the layperson's view of probability that is of immediate concern in this paper. A model of the layperson's concept of probablity will be inferred from a set of indepth interviews and then tested in a second set of interviews. First, it will be helpful to briefly review the scientific status of probability so that the layperson's concept, once specified, can be understood with respect to the various theoretical schools of probability.

Facets of Probability

Our present concept of probability took form around 1660 when Pascal, Huygens, Leibniz, Fermat, and others somewhat independently developed formalizations for treating such diverse phenomena as games of chance, legal decisions and annuities. In a letter to Fermat, dated October 27, 1654, Pascal reviewed their independently-arrived-at solutions to a problem of how to divide stakes in an interrupted game of chance. He demonstrated that while, on the surface, their approaches appeared different, they were, in fact, comparable. He concluded with a statement that, in retrospect, seems prophetic: "Now our harmony has begun again" (Maistrov, 1974, p. 39). The harmony was two-part, consisting of the acknowledged need to discriminate between independent and dependent events, and of the addition and multiplication rules which allowed for the calculation of the union and intersection of independent events.

What came into being at that time was, to strain the metaphor, a new tune. What was not so new were the lyrics—"How probable is it that..." Since that time we have been plagued with a concept of probability that has at least two different but related aspects. On the one hand it is a somewhat vague epistemological notion of the degree to which some belief is held to be true; on the other, it refers, in a precise way, to the relatively stable frequencies exhibited by some phenomena. The difference between these two can be illustrated by comparing the two propositions below:

1) "My confidence is X that the statement, 'I will
   live to the age of 60,' is true."

2) "Accoring to life expectancy tables, my chances of
   living to the age of 60 are X."

The first is a combination of two propositions--"I will live to the age of 60" and, "My confidence is X that the statement is true." The nature of the expressed belief is not specific, but we can assume that it derives, legitimately or not, from a variety of sources. This is termed epistemological probability.

The second proposition is different in that there is no question as to the source of the number: It is derived from available frequency data. This is aleatory probability. (See Hacking, 1975, for a discussion of these two meanings of probability and for a possible explanation for this dual usage of the term.)

Not only have these two meanings clung tenaciously to the same word, but, since the time of Pascal, several schools have sprung up on both sides of the probability street. On the aleatory side, three schools have developed:

Classical Theory

According to the classical definition, which was prevalent until the time of Bernoulli, the probability of an outcome is simply the ratio of the number of favorable possibilities to the total number of basic alternatives. Thus, the probability of rolling a 3 on a 6-sided die is 1/6 since only one possibility is favorable to the outcome, while the other five are not. An obvious assumption, and the major limitation of this definition, is that the outcome alternatives must be equally likely.

Frequentist Theory

According to a frequentist theory (e.g., Reichenbach, 1949; von Mises, 1957) the probability of an event is its limiting frequency of occurrence in an infinite series of trials. Thus the probability of rolling a 3 on a particular die is the relative number of occurrences if the die were rolled an infinite number of times.

Propensity Theory

To the frequentist, the probability of an event refers to its frequency in the long run. One cannot, therefore, sensibly talk of the probability of a single occurrence. According to propensity theorists (e.g., Hacking, 1965; Mellor, 1971), however, the probability of rolling a 3 is an inherent, physical characteristic of the die. As a result, probability is viewed as something that belongs to each individual trial.

On the epistemological side of probability, two major schools can be distinguished:

Personalist Theory

According to this view (e.g., Ramsey, 1931; Savage, 1954), all probability is a matter of personal judgment, and is thus subjective. By assuming that such judgments are internally consistent, however, a measurement technique is hypothesized that involves an exhaustive ordinal comparison of a person's judgments. Using Bayes' theorem as a normative algorithm for adjusting these judgments when given new information, the theory can be used as a model of rational decision-making.

Logical Relations Theory

According to these theorists (e.g., Carnap, 1950; Jeffreys, 1948), the confidence in a proposition is the extent to which it is logically implied by some other proposition. Since the relations between propositions of this type are defined formally and do not rely on the specific content of the propositions, the theory is viewed as an objective as opposed to subjective theory. (For an in depth treatment of these various theories, see Mackie, 1973.)

While probability theorists have been concerned with the internal coherence of their theories, psychologists have, since the late 1950's, become increasingly interested in determining whether formal theories of probability could be used to model human decision-making. The extent to which actual human behavior conformed to the normative statistical solutions thus became an important and heavily investigated question.

Peterson and Beach (1967), in their review of the research, concluded that probability and statistical theory provide a good first approximation of actual human decision-making under uncertainty. Subjects seemed to be quite good at estimating descriptive parameters such as means and variances, and somewhat less able in tasks involving statistical inference. Peterson and Beach concluded their review by stressing the need for a more descriptive approach and the construction of psychological theories that would better account for human probabilistic reasoning. Since that time, Daniel Kahneman and Amos Tversky have been the most prolific in generating explanations that account for non-normative statistical behavior. In a series of articles, they have suggested that because of limited information-processing capabilities, people use various judgment heuristics or rules that allow them to summarize large amounts of data and quickly arrive at decisions (Kahneman & Tversky, 1972, 1973; Tversky & Kahneman, 1973). While these heuristics usually produce adequate estimates, limitations in the amount and type of information that they are sensitive to leads to predictable judgmental errors in some situations. These heuristics, for example, have been used to explain the gambler's fallacy, insensitivity to sample size, and misconceptions involving random sequences and regression effects (Tversky & Kahneman, 1974). That these heuristics have been integrated into attribution theory and inspired some new lines of investigation in the field of social psychology is evidence of their generalizability (cf. Nisbett & Ross, 1980).

However, in terms of describing an informal theory of probability, these studies have three major limitations. First, they have involved mostly questionnaire studies in which reasoning processes are inferred on the basis of subjects' final answers to problems dealing with uncertainty. No direct information regarding how the answers were derived is generally obtained or reported. Second, only measures of group performance are typically reported, which masks informative individual differences. Third, the judgment heuristics are not alternative theories of probability. Rather they are viewed as short-cut procedures for arriving at probability judgments. The question of the underlying theories people might hold is left unaddressed. Yet the assumption inherent in asking subjects to provide numerical probabilities in response to questions is that the subjects' view of probability is consistent with formal theories. If this is not the case, subjects' responses cannot be easily interpreted.

More recently, Kahneman and Tversky (1982) have attempted to describe several variants of probability as suggested in the usage of the term in natural language. Similar attempts have been previously made (Lucas, 1970; Mackie, 1973; Toulmin, 1958). The belief that informal theories of probability can be inferred from an analysis of language is in the spirit of Hacking's (1975) analysis and is a major assumption in the method to be used in this investigation of informal conceptions of probability. A brief review of the objectives and assumptions of this thesis follows.

Objectives and Assumptions

The fact that the status of the concept of probability is disputed by theorists provides some clues as to the nature of the difficulties encountered in this study. No doubt the varieties of informal theories are staggeringly numerous if described in detail. I proceed on the assumption that the majority of people can be described as falling into a few categories. I assume, too, that peoples' notions of probability are, for the most part, internally consistent and valid in the context of their environment. By exposing them to a variety of problems, I have attempted to determine if and at what points their approaches to the problems change, and in this way gain access to their "informal probability axioms." This approach is ethnographic in spirit in that I attempt to provide phenomenal (world-as-perceived) as opposed to nomenal (world-de facto) descriptions (cf. Magoon, 1977; Wilson, 1977; Marton, 1978). I draw heavily on the image of probability as a concept that is "rooted in a dialogue" (Lucas, 1970, p. 9), that "exists in discourse and not in the minds of speakers" (Hacking, 1975, p. 16). Using the metaphor of a conceptual space much the same as Kuhn (1962) talks of paradigms or Foucault (1973) of epistemes, Hacking suggests that

> concepts are less subject to our decisions than a positivist would think, and that they play out their lives in, as it were, a space of their own.... All those who...employ the concept use it within this matrix of possiblities. (p. 15)

In order to explore the nature of "probability" as it exists in discourse, in depth interviews were employed. The study involved two interview sessions. In the first (Interview 1), 16 subjects were given a selected set of questions dealing with various aspects of probability. Videotapes of these interviews were then analyzed, and aspects of subjects' reasoning that were at variance with formal probability theory were identified. An hypothesized internal coherence among these identified statements was formalized in a three-feature model of

probabilistic reasoning termed the outcome approach. Subject responses that could be regarded as indicators of reasoning according to one or more features of the model were then coded. On the basis of this coding, a score was generated for each subject that reflected the degree of adherence to the outcome approach. Interview 2 was then conducted to test the validity of the outcome approach. The same subjects were given a different set of problems for which specific predictions had been made on the basis of their scores on the first set of interviews.

METHOD: INTERVIEW 1

Subjects

Seventeen undergraduate students at the University of Massachusetts, Amherst, volunteered to participate in the study by placing their names on a sign-up sheet that was posted in the psychology building. Subjects were offered a choice of either extra course credit or $5.00 for their participation. They were informed that they would be asked to talk about various situations that involved uncertain outcomes, and that they would be asked to participate in a similar study the following semester. One interview was terminated before completion when it was thought that the subject was experiencing a high degree of stress. Data from this interview were not analysed. Information concerning the sex, major, and math and statistics background of each subject is included in Table 1.

Insert Table 1 about here

Procedure

Setting

Subjects were interviewed individually by the author. Upon entering the room, subjects were asked to read and sign a consent form which described the study as being motivated by the desire to better understand the kinds of relevant knowledge students possess before or after having completed a statistics course. They were instructed that they would be given several problems that would require them to predict an outcome in situations involving uncertainty. They were told that the particular answers they gave were of less interest than their reasoning that led to the answer. Accordingly, they were instructed to "think aloud" as they attempted to solve each problem, verbalizing their thoughts as they occurred rather than attempting to reconstruct them at some later time. A felt pen and piece of paper were provided, and subjects were told that they could use these for any figuring or drawing that would help them to think or communicate their thoughts about the problems. Subjects were also informed that the interview would be videotaped, and the recording equipment was in full view.

Problems

Twelve problems were initially developed and piloted in twelve interviews with other subjects. These problems were chosen to vary on several dimensions that either were regarded as important within various theoretical perspectives (e.g., repeatability and independence of trials) or were thought to be potentially important in informal theories (e.g., past vs. future outcomes and outcome utility). Five problems were finally selected for inclusion in the first set of interviews. However, subjects' responses to only three of these problems will be treated in this report. These problems are presented below. (The organization of the problems into paragraphs is meant to indicate clusters of questions that were related and does not have any other meaning vis-à-vis the way questions were presented during the interview.) Standardized probes that were asked of most subjects are also included. Non-standardized probes for the most part consisted of requests to clarify or repeat a statement and reminders to verbalize. However, unique probes spontaneously developed to test hypotheses about subjects' reasoning were also employed. The interview format, therefore, could best be described as in depth (cf. Konold & Well, 1981) in which extensive probing by the interviewer is allowed, provided the probes do not direct subject thinking. (See Konold, 1983, for a description of the other two problems used and also for a complete transcript of both interview sessions with Subject 11.)

Weather problem. What does it mean when a weather forecaster says that tomorrow there is a 70% chance of rain? What does the number, in this case the 70%, tell you? How do they arrive at a specific number?

Suppose the forecaster said that there was a 70% chance of rain tomorrow and, in fact, it didn't rain. What would you conclude about the statement that there was a 70% chance of rain?

Suppose you wanted to find out how good a particular forecaster's predictions were. You observed what happened on ten days for which a 70% chance of rain had been reported. On three of those ten days there was no rain. What would you conclude about the accuracy of this forecaster? If the forecaster had been perfectly accurate, what would have happened? What should have been predicted on the days it didn't rain? With what percent chance?

Numbers are often assigned to various events like elections, sporting events, causes of death. For example, you might hear something like, "A person's chances of dying before the age of 40 are 25%." What does the 25% tell you? Or you might hear, "The Equal Rights Ammendment has a 25% chance of being ratified by the June, 1982 deadline." What does the 25% in this case tell you?

Misfortune problem. I know a person to whom all of the following things happened on the same day. First, his son totalled the family car and was seriously injured. Next, he was late for work and nearly got fired. In the afternoon he got food poisoning at a fast-food restaurant. Then in the evening he got word that his father had died. How would you account for all these things happening on the same day? Have you ever had something very unlikely happen to you? To someone you know? How do you make sense of a day when everything seems to go wrong?

Bone problem. I have here a bone that has six surfaces. I've written the letters A through F, one on each surface. (Subject is handed the bone which is labeled A, B, C, and D on the surfaces around the long axis, and E and F on the two surfaces at the ends of the long axis.) If you were to roll that, which side do you think would most likely land upright? How likely is it that x will land upright? (Subject is asked to roll the bone to see what happens.) What do you conclude about your prediction? What do you conclude having rolled the bone once? Would rolling the bone more times help you conclude which side is most likely to land upright?

(Subject is asked to roll the bone as many times as desired.) What do you conclude having rolled the bone several times? How many times would you want to roll the bone before you were absolutely confident about which side is most likely to land upright?

One day I got ambitious and rolled the bone 1000 times and recorded the results. This is what I got. (Subject is handed the list which showed A-50, B-279, C-244, D-375, E-52, F-0.) What do you conclude looking at these? Would you be willing to conclude that D is more likely than B? That B is more likely than C? That E is more likely than A? If asked what the chance was of rolling a D, what would you say?

I'm going to ask you to roll the bone ten times, but before you do, to predict how many of each side you will get. How did you arrive at those specific values? (Subject rolls the bone and notes the results of each trial on the sheet of paper. After the 8th trial the subject is asked:) What is your best guess of what you will get on the next two rolls? (After the last trial the subject is asked:) How do you feel about your predictions? If you were going to roll the bone ten more times, what would you predict that you would get?

The problems were presented orally by the interviewer. Two orders of presentation were used, the order being alternated on each successive interview. Order A was the sequence Weather, Bone and Misfortune followed by the two other problems. Order B was the reversed sequence.

Each interview required approximately one hour. Following the interview, subjects were told that questions about the project would be answered following the second interview which would be conducted during the next semester.

ANALYSIS AND DISCUSSION: INTERVIEW 1

The aim of this project was to articulate an informal approach to probability that would allow peoples' statements and expressed beliefs concerning probability to be seen as interrelated and, ideally, logically consistent. The videotaped interviews and rough transcripts made from the videotapes provided a set of statements from which such a theory could be developed.

The analysis comprised two general and interrelated stages of hypothesis formation. The first stage involved repeated reviews of the transcripts and videotapes with the purpose of answering questions of the form, "What is this subject trying to say about x?" An answer to such a question is regarded as a descriptive hypothesis (cf. Konold & Well, 1981)--descriptive in the sense that it simply attempts to restate what the subject was communicating, and an hypothesis because we can never be sure that we understand what was meant to be communicated. Attention was especially focused on statements that seemed inconsistent with any formal theory of probability and that were common to several subjects.

The second stage was to attempt to infer from the collection of statements or descriptive hypotheses a set of underlying "axioms" from which the statements could be deduced. This stage is conceived by Konold and Well (1981) as one involving the formulation of interpretive hypotheses--interpretive in that the attempt is made to go beyond what the subject is explicitly communicating and to infer what tacit knowledge the subject must possess in order that their expressions appear internally consistent.

In this chapter I will describe an informal approach to uncertainty that was inferred from an analysis of the interviews and which I have labeled the "outcome approach." This approach will be decribed as one in which the primary objective is to predict the outcome of an individual trial. Given this objective, questions explicity asking for the probability of an outcome are translated into questions of whether, in fact, the outcome will occur. To give an initial impression of the approach, two composite interviews are juxtaposed below. On the left is a prototype of the outcome approach; on the right, a prototype of a frequency interpretation. These prototypes are assemblages of excerpts from several subjects (as noted) and should be regarded as ideal characterizations. While a few of the subject protocols will closely resemble one or the other of these prototypes, most subjects, in fact, could best be described as in an intermediate stage somewhere between their previously-held outcome approach and a recently-exposed-to frequency interpretation. Many of the subjects interviewed had taken a statistics course in a university psychology department. Since the statistical approach of the social sciences is almost exclusively in the tradition of Fisher or Neyman-Pearson, subjects' exposure to formal probability had been frequentist in nature.

Outcome Approach	Frequency Interpretation
Weather Problem	
I: What does it mean when a weather forecaster says that tomorrow there is a 70% chance of rain?	
S5: What it means is they can see all these cloud patterns forming and moving into a particular area, but they're (1) not as dense as, say, a hurricane where you can absolutely predict where it's going to go. 100%--that means it was a total cloud	S4: 70% means that the chances that it will rain are seven out of ten, according to him.

thing coming over the area.

I: What does the number, in this case the 70%, tell you?

(2) S6: Well, it tells me that it's over 50%, and so, that's the first thing I think of. And, well, I think of the half way mark between 50% and say 100% to be like, well, 75%. And it's almost that, and I think that's a pretty good chance that there'll be rain.

S4: Well, it says that there's a 30% chance that it isn't going to rain.

I: Suppose the forecaster said there was a 70% chance of rain tomorrow and, in fact, it didn't rain the next day. What would you conclude about the statement that there was a 70% chance of rain?

(3) S12: Well, that maybe they just fouled up. Or during the night, the precipitation or something changed in a different direction because of other outside factors.

S4: Well, on the basis of just the sample, I think an unrational response would be that the prediction was wrong. But, in fact, 30% is a pretty good probability that it's--it's not miniscule that it's not going to rain.

I: Suppose you wanted to find out how good a particular forecaster's predictions were. You observed what happened on ten days for which a 70% chance of rain had been reported. On three of those ten days there was no rain. What would you conclude about the accuracy of this forecaster?

(4) S3: Well, I suppose he probably should do better than that. I assume they're trying their best. They're not trying to feed you wrong information.

S2: He was exactly right. Seven out of ten times is 70%. And he concluded 70% chance of rain all ten times. So--70% of all the time.

I: What should have been predicted on the days it didn't rain?

(5) S12: Well, he could either have said that there's a chance that it might rain rather than being more definite, or just said "mild," you know, "some clouds," or something like that rather than being specific.

Misfortune

I: I know of a person to whom all of the following things happened on the same day.... How would you account for all these things happening on the same day?

(6) S5: I'm trying to figure out if the order you gave me was the order that they happened, or if his father died--or he went out to a restaurant with his family and they got food food poisoning, and because he was sick, while he was driving he smashed up the car. His father died in the accident, and he was on his way to work so he was late.

S2: It's arbitrary, somewhat. It just occurred. I don't see any other way I could explain how they all occurred on the same day. I could see how if the guy totalled his car, he'd probably be late for work. Even though it's unlikel, to occur, like if it only happens 1 in 1000 times, if you live 1000 days the odds are it's going to happen to you. So even though it's unlikely for an every-day occurrence, when you consider all the days that you live, it's not so unlikely.

Bone Problem

I: If you were to roll this, which side do you think would most likely land upright?

(7) S9: Wow. If I were a math major this would be easy. B is nice and flat, so if D fell down, B would be up. I'd go with B.

S2: I don't think I could tell you without rolling it. This is not like a die, and I think that there is no way of me knowing personally without

		experimentation. S4: I could only give my best guess. I'd have to say B up.

I: And about how likely do you think B is to land upright?

(8)	S9: I wouldn't say it's much more likely. It depends on the roll, I think.	S4: I'll give a big bias to B. I'll say 33%.

I: So what do you conclude having rolled it once?

(9)	S10: Wrong again. [B] didn't come up.	S15: I don't conclude anything. Can I roll it again?

I: Would rolling it more times help you conclude which side, if any, was most likely to land upright?

(10)	S9: No. I don't know. I think it's difficult to decide which is more likely. I don't see how you really can, just by looking at it. That's my opinion.	S1: Oh definitely. I mean that's the only way I could tell for sure. I think the only way with a thing like this is to just keep rolling it and just record the results.

These prototypes were assembled and juxtaposed primarily to highlight three features of the outcome approach:

a) the tendency to interpret questions about the probability of an outcome as questions about the outcome of a single trial;

b) the use of probability values as a means of arriving at a yes or no decision which, after-the-fact, can be evaluated as having been either right or wrong; and

c) the reliance on causal as opposed to statistical or chance

explanations.

In the remainder of this section the three features will be more formally described and exemplified by referring to the numbered excerpts in the above prototype interview. The features will also be contrasted to corresponding components in the frequency and personalist theories of probability.

Characteristics of the Outcome Approach

Outcome-oriented subjects, when asked the probability of repeatable events (such as in the Bone problem), believe they are being asked about the results of a single trial. This tendency to focus on the outcome of a single trial will be referred to as the single-trial feature. This contrasts with the frequency interpretation where the primary focus is a sample of trials, and in which probability is conceptualized as the relative frequency of occurrence of an outcome in a large sample.

Closely related to the single-trial feature is the objective of the outcome approach which is to predict outcomes of trials in a yes-or-no fashion. This objective will be referred to as the decision feature and, again, contrasts with the frequentist interpretation in which the objective usually is to predict the average value or percent of some outcome in a large number of trials. A prediction in the frequency approach does not involve a yes or no prediction as it does in the case of the outcome approach, but rather, is an estimate of the long-run frequency of occurrence of a particular outcome.

The outcome approach will be seen as more similar to a personalist

interpretation since in both cases a probability value gauges the degree
of belief that a particular outcome will occur on a given trial.
However, a personalist interpretation does not necessarily involve
yes/no predictions. A personalist, having made the statement, "The
probability of x is p," would attempt to verify the accuracy of this
proposition by determining what percent of events assigned the
probability p actually occur. For example, if a personalist estimated
the probability of several independent and unique events to be .60, and
these were "good" estimates, it would be expected that approximately 60%
of these outcomes would occur, while 40% would not. In the outcome
approach, a prediction is only "good" if the predicted outcome occurs: A
prediction has no specific meaning in relation to future or past
predictions of the same or similar outcomes.

Predictability of Individual Trials

In this subsection the single-trial and decision features are
considered together. An explanation for why they are not being
discussed separately is necessary for understanding coding procedures
which will be described later, and also for helping to clarify the
perceived relation between these two features.

Though aspects of subjects' reasoning can be separately described
as consistent with either the single-trial or the decision feature, in
fact, in these protocols, evidence for these two features almost always
occurs together in the same sentence or proposition. Thus, they appear
as a functional unit: Outcome-oriented individuals see as their task

predicting in yes/no fashion the results of a particular trial. The
virtually perfect co-occurrence of statements that support the
single-trial and decision features may reflect a logical connection
between the two: If the single-trial is viewed as the appropriate unit
in the treatment of uncertainty, predictions that involve average number
of outcomes make little sense. Average outcomes can only be computed
and used to describe the probability of a single trial when a series of
trials is seen as a legitimate unit of analysis over which an average
can be computed.

In the outcome approach, predictions of individual trials thus take
the form of "yes," "no," and occasionally "I-don't-know" decisions of
whether or not a particular outcome will be observed. Four of the
subjects translated the statement "70% chance of rain" into the more
definitive and qualitative statement, "It's going to rain." Typically,
this translation was accomplished by using the probability range of 0%
to 100% to form a decision dimension, with 100% corresponding to "yes,"
0% to "no," and 50% to "I don't know." (See Excerpt 2.) Intermediate
values are ultimately associated with one of these three anchor or
decision points according to a vague and variable proximity criterion.
Thus, 70% is considered sufficiently above 50% to warrant identification
with 100% or "yes," with perhaps some associated expectation of error.
Given this qualitative (yes/no) interpretation of the probability range,
50% was not viewed as a predictive forecast by three of the subjects,
but as an admission by the forecaster of total ignorance about the
outcome.

Using probabilities to arrive at decisions in this way, however, does not necessarily imply that the meaning of the values as probabilities is not also available. A frequentist or personalist might hear the statement, "There is a 70% chance of rain today," and conclude that they had better take an umbrella. But they would know that if they looked at the record of those days for which a similar prediction was made, on approximately 30% of them it would not have rained. One of the probes used in the Weather problem inquired about the accuracy of a forecaster who had predicted 70% chance of rain for ten days, when in fact, no rain was recorded on three of the ten days. According to probability theory, seven days of rain out of ten is the most likely outcome given an accurate 70% forecast on each day. Three of the subjects' responses were consistent with this reasoning. Nine of the subjects, however, felt that the forecaster was only "pretty accurate," suggesting that there was room for improvement. (See Excerpt 4.)

All but one of these nine subjects were also asked what should have been predicted on the days it didn't rain. In every case, subjects suggested that the percentage given should have been lower than the 70%, and usually lower than 50%. (See Excerpt 5.) This implies that on the days it didn't rain, the prediction of a 70% chance of rain was incorrect. That subjects see as their task the prediction of individual trials is further evidenced by this tendency to evaluate a prediction as either right or wrong after the occurence of a single trial. In the Weather problem, a situation was given where a prediction of 70% chance of rain had been made for a day on which no rain fell. Asked what they would conclude about the accuracy of the statement that there was a 70% chance of rain, six of the subjects responded that the statement must have been incorrect (as exemplified in Excerpt 3).

These evaluations of single-trial predictions as either right or wrong are inconsistent with a frequency interpretation which is concerned with a sequence of trials rather than with the occurrence or non-occurrence of a single predicted outcome. In the context of the outcome approach, however, a yes or no prediction of a single trial is the objective. Also, given a yes or no prediction, it is appropriate to evaluate the prediction as either right or wrong once the outcome of the trial is known.

Subjects' performance on the Bone problem provides further evidence of the pervasiveness of this tendency to evaluate outcome predictions as right or wrong. When asked to guess which side of the bone was most likely to land upright, nine of the subjects made comments to the effect that their prediction of which side would most likely land up was either right or wrong after one roll of the bone. (See Excerpt 9.)

Evidence from both the Bone and Weather problems (summarized in Table 2) supports the claim that subjects take questions explicitly requesting probabilities and encode them into ones that ask instead for a decision of which alternative will occur on a particular trial. Once the trial has been conducted, these predictions can retrospectively be evaluated as either right or wrong. When probabilities are provided, as in the Weather problem, they are not interpreted as probabilities per se, but as values which can be used to partition a space into yes, no, and I-don't-know decision regions.

Insert Table 2 about here

Predicting Outcomes From Causes

In this subsection it will be argued that outcome-oriented individuals arrive at predictions through consideration of factors that would cause or bring about a particular result. Thus, the outcome approach will be portrayed as involving a causal as opposed to a chance interpretation of uncertain events, the latter being characteristic of formal probabilistic reasoning. A few comments about how uncertainty is viewed within a formal framework will help clarify the distinction between causal and chance explanations.

First, it needs to be stressed that a formal probabilistic approach does not necessitate the denial of underlying causal mechanisms in the case of chance events. Hypothetically, one can imagine describing the last in a series of 100 tosses of a fair coin in sufficient detail such that it could be seen to be determined by events which preceeded it. In practice, however, a causal description is often seen as impractical if not impossible (e.g., von Mises, 1957, p. 208-209). Accepting a current state of limited knowledge, a probabilistic approach adopts a "black-box" model according to which underlying causal mechanisms, if not denied, are ignored. Abandoning a specific, mechanistic analysis of cause and effect, a chance model gains its power from observations related to the fact that regularities occur over series of trials independent of specific causal agents. As will be illustrated in this subsection, a mechanistic model is not abandoned in the outcome approach. The goal of predicting the results of individual trials in a yes/no fashion would, in fact, seem to imply the possibility of determining beforehand the results of each individual trial. This could only be accomplished through an analysis of the appropriate causal mechanisms.

In the Weather problem subjects were asked to explain what the specific number in the proposition "70% chance of rain tomorrow" means. Three of the subjects (3, 9, 5, the latter having also given a frequentist account) suggested that the 70% was a measure of the presence of factors that would produce rain such as humidity and cloud cover. (See Excerpt 1.)

In the Misfortune problem, eight of the subjects gave other than chance explanations for the co-occurrence of the several low-probability events. Six of them tried to embed the events in a causal sequence such that each could be seen to have been a direct result of a preceding event. (See Excerpt 6.) Five of the subjects relied on explanations that involved external causal agents such as God, the stars and bad luck.

In the Bone problem, five subjects expressed reservations about whether additional trials would be helpful in determining which side was most likely to land upright. (See Excerpt 10.) Three subjects did not use the data provided from the results of 1000 trials in predicting the results of 10 trials. Eight subjects attributed variations among trials to the way the bone was rolled. Table 3 summarizes subjects' performance with respect to the causal feature in the three problems. The data are indicative of a tendency in subjects to believe that chance events can be analyzed in a mechanistic or causal framework.

Insert Table 3 about here

In this section an informal approach to probability has been suggested according to which subjects' responses to the problems could be viewed as reasonable. The informal approach has been described as "outcome-oriented" since the primary focus is the individual trial. Arriving at a prediction often involves an analysis of the presence of factors which would tend to cause individual outcome alternatives. Numeric values that may be associated with a prediction are measures of the confidence that the predicted outcome will occur, as well as measures of the extent to which causal agents affect that outcome. When probabilities are given to the outcome-oriented individual, they are interpreted consistently with the two characteristics mentioned above, and are recoded into a yes/no or I-don't-know decision according to their distance from the corresponding values of 100, 0, and 50%.

These features have been presented in a way that highlights their logical connections and makes it plausible that they are manifestations of a general approach to probabilistic reasoning. However, more evidence is needed to establish that such an approach actually describes subjects' reasoning. If these three features are related components of such a general approach, two patterns ought to be evident in the data. First, evidence for a particular feature ought to be reliable across problems: A subject who makes an evaluative (right/wrong) response in the Bone problem ought to be more likely to make a similar response in the Weather problem. Second, evidence for the features ought to cluster together: A subject who adopts a causal approach to determining a probability ought to be more likely to make an evaluative response in the context of the occurrence of a predicted outcome. These questions are explored below.

Correlations Within and Among Features

Within features. It was possible to determine the consistency of the causal feature across all three of the problems. However, the only other response-type that occurred in more than one problem was the evaluation of predictions, which was observed in both the Weather and Bone problems.

Scores for the evaluative response in the Bone problem were generated by scoring 2 points if subjects made at least one statement to the effect that their prediction was right or wrong. In the case of the Weather problem, corresponding scores were generated by scoring a) 2 points if subjects said that the forecaster was wrong for having predicted rain when, in fact, it did not rain, and b) 2 points if the 7-out-of-10 prediction was regarded as "pretty accurate" or 1 point if subjects were undecided between the "pretty accurate" and "perfect" evaluation. (See Table 2.)

Scores for the causal feature in the Bone problem ranged from 0 to 4, 1 point being scored for each category that was checked in Table 3. Corresponding scores for the Weather and Misfortune problems ranged from

0 to 2. For the Weather problem, 1 point was scored for each category that was checked in Table 3. For the Misfortune problem, a score of 0 indicated that only a chance explanation had been given or had been preferred to a non-chance explanation; 1 if both a chance and a causal explanation were given, but no preference was expressed for the former; and 2 points if only causal explanations were given.

Product-moment correlations were calculated and the significance of the values were evaluated using one-tailed t-tests. The correlation between the evaluative responses in the Bone and Weather problems was $r = .423$ which was not significantly different from 0. Correlations among the causal features were: Bone-Weather $r = .634$, $p<.005$; Bone-Misfortune $r = .477$, $p<.05$; Weather-Misfortune $r = .460$, $p<.05$.

Among features. In the analysis of the interviews, the decision and single-trial features were not analyzed or coded separately since their co-occurrence was virtually perfect. Accordingly, the correlations that are examined in this section are those among the a) evaluative and b) yes/no predictions associated with the decision feature and c) the causal feature. Scores for the among-feature comparisons were obtained by combining the features scores of the individual problems. The evaluation-of-prediction scores ranged from 0 to 6, the scores for the Bone and Weather problems having been added together. For the causal feature, the scores on the Weather, Misfortune, and Bone problems were added together, giving a possible range of from 0 to 8. The yes/no prediction scores were based only on performance in the Weather problem. They ranged from 0 to 3, 1 point being scored for each category checked in Table 2.

Product-moment correlations were calculated and evaluated as in the within-feature analyses. The causal and evaluative responses were highly correlated ($r = .762$, $p<.0005$). The yes/no predictions and causal responses were also related ($r = .443$, $p<.05$). However, the yes/no predictions and evaluative reponses did not prove to be significantly related ($r = .275$).

In spite of the restricted sample size and the fact that the feature scores were based on very few criteria, the correlational analyses provide evidence that suggests that, as a whole, the features as decribed are both consistent across problems and cluster together in subject protocols. These correlations support the hypothesis that some subjects whose responses are inconsistent with and incomprehensible from the prespective of formal probability theory can be viewed as reasoning coherently within the context of an alternative (outcome-oriented) approach to uncertainty.

However, there are at least two bases for skepticism. First, the logical connections which were developed and the correlational evidence were obtained from the same data set and thus cannot be viewed as separate sources of evidence. Second, it may be that the three features are common but unrelated notions held by those who are unfamilar with formal probability theory, and their co-occurrence reflects primarily this lack of formal instruction.

With these critisisms in mind, a second set of interviews was conducted. The same subjects were given four new problems and interviewed as before. Prior to the interview, specific predictions were made to test the validity of the outcome approach. These predictions were made on the basis of an outcome score that was derived for each subject from the coded results of Interview 1. Rather than describing these predictions here, it will be more convenient to first present the methodology and the problems. The predictions will be elaborated in the process of presenting and discussing the results of Interview 2.

METHOD: INTERVIEW 2

Subjects

Twelve of the original sixteen subjects returned to participate in the follow-up interviews. The other four could not be located. Subjects were offered a choice of either extra course credit or $10.00 for participating. Approximately five months had elapsed between Interviews 1 and 2. Additional math or statistics instruction that subjects had received during this interval is noted in Table 1.

Procedure

Setting

Initial instructions to subjects were nearly identical to those given in Interview 1. Subjects were told that they would be given several new problems that were similar to the last set in that they involved predicting outcomes in situations of uncertainty. They were reminded to "think aloud" and to use the pen and paper for any figuring they might want to do.

Problems

Four problems were employed. The Cab problem (a problem in Bayesian inference) had been used in previous research (Well, Pollatsek & Konold, 1983). The remaining three problems were developed and then standardized in 14 pilot interviews. All four problems are presented below in the order they appeared in the interview.

> Cab problem. (Subjects were asked to read the Cab problem aloud.) "A cab was involved in a hit-and-run accident at night. Two cab companies, the Green and the Blue, operate in the city. You are given the following data:
>
> (i) 85% of the cabs in the city are Green and 15% are Blue.
>
> (ii) A witness identified the cab as a Blue cab. The court tested his ability to identify cabs under the appropriate visibility conditions. When presented with a sample of cabs, half of which were Blue and half of which were Green, the witness made correct indentifications in 80% of the cases and erred in 20% of the cases.
>
> What is the probability that the cab involved in the accident was Blue rather than Green?" (After subjects give a numerical response they are asked:) How did you arrive at that number?
>
> Suppose the information in (i) were reversed such that 85% of the cabs in the city were Blue and 15% were Green. The witness, as before, identified it as Blue and was 80% correct in the test situation. In that case, what would you say the probability was that the cab involved in the accident was Blue?

Bone-2 problem. Last time you were asked which side of this bone you thought would most likely land upright. Do you remember which side you concluded? (The bone is held far enough away so that the labels cannot be read.) I'm going to ask you the same question again. And to give you something to base your answer on, I'll offer you any one of the following pieces of information. (Subject is shown the list as the interviewer reads the items.)

1-A measure of surface area of each side.
2-The results of 100 rolls made by 16 people.
3-The results I got in 1000 rolls.
4-A drawing of the bone showing the center of gravity.
5-The bone to look at.
6-The results on your last 10 rolls.

Which one would you like? Why did you chose that? If you could have a second piece of information, which would you choose? Why did you choose that? (Subjects are given both choices unless item 4 has been picked. In that case, they are told that the drawing is not available, and to pick another item. The estimate of surface area is in square inches: A=.028, B=.078, C=.065, D=.169, E=.018, F=.031. The results of 100 rolls were: A=7, B=32, C=21, D=35, E=5, F=0.) If you rolled the bone, which side do you think would most likely land upright? What is the probability that x will land upright? (Subjects are asked to predict what they would get in ten trials, then the trials are conducted as in Interview 1.)

Painted-die problem. I have here a six-sided die. Suppose I told you that there was a possibility that it was loaded--that it had been altered so that one side was slightly more likely than the others to come up. Could you determine whether or not it was loaded? How? Would rolling it help you determine whether it was loaded? Suppose you rolled it 24 times and got the following results: (Subject is shown the results as the interviewer reads them.) 1=5; 2=2; 3=8; 4=2; 5=4; 6=3. What would you conclude?

In fact, the die is not loaded. Suppose I painted five of the surfaces black and the other one white. If I rolled the painted die six times, would I be more likely to get six blacks or five blacks and one white? If I rolled it 60 times, how many times would you expect the white surface to come up? (This probe was originally worded, "On the average, how many times would you have to roll the die until you got a white?" After the third interview, it was changed to the present form, which was easier for subjects to understand.)

Obviously, I haven't painted the die. But I do have five black stones and one white one. (The stones were identically shaped pieces from a board game which subjects had used in a

previous problem in Interview 1.) Suppose I put these in this cup and shook it up really well. Then I reached in without looking and drew one out, wrote down the color, replaced it, shook it up again and kept drawing like that. (This is demonstrated as it is explained.) Would that be the same as rolling the painted die? If I rolled the die several times and recorded what I got, and I drew stones and recorded those results, could you tell from looking at the results which I got from rolling the die and which from drawing stones? I'm going to draw six stones from the cup, but first ask you to predict what I'll get? (Stones are sampled, and before shown the results of each trial, the subject is asked both to predict the color that has been drawn, and the probability that it is that color.)

Modelling problem. You agreed that we could create a model of the painted die by drawing stones from a certain cup--that that would give comparable results. Would there be a similar way that we could make a model of the bone so that instead of rolling the bone we could pick something out of a container and get the same kind of results?

(Subjects are given the following probes successively until they agree upon a model or reached the end of the list:)

1-How about if we put six stones which have been labeled A through F in this cup and sampled from it as we did before?

2-Is there some container that I could fill with some number of lettered stones that would give results similar to rolling the bone?

3-Suppose we took the bone to a statistician and, however it is done, the following probabilities were calculated for each side: (Subjects are shown the list as the interviewer reads it.) A was 5 out of 100, or 5%; B was 29 out of 100, 29%; C, 24; D, 37; E, 5; and F, 0. So we took a big can and first put five of these stones which have been labeled A inside. (A large can and six small containers filled with labeled stones is produced.) Then we took 29 Bs, 24 Cs, 37 Ds, and 5 Es, and put them in the container also. Then we shook it up and sampled from it as before. Do you think that would give results comparable to rolling the bone?

4-Suppose we rolled the bone and, say, we got a B. We took a stone labeled B and put it in the container. Then we rolled the bone again, and similarly, whatever we got, we put the appropriately labeled stone in the container, and we did that over and over. Would we reach a point when it would make no difference if we rolled the bone or drew from the container we had filled?

(When, and if, subjects agree upon a model of the bone, they are asked the following questions:) If I rolled the bone 100 times and kept track of what I got, then I drew 100 times from this can filled with the labeled stones, and I showed you

> the results from both, could you tell from looking at the results which I got from rolling the bone and which from drawing from the container? In those 100 trials with the bone and the container, do you think with one of those I'd be more likely than with the other to get no Es? Do you think I'd be more likely with one of those to get more Ds in 100 trials than with the other?

The problems were presented orally by the interviewer, and in the order as specified above. The interview format was the same as in Interview 1.

The interviews required approximately 40 minutes. Following the interview, questions about any of the problems in either session were answered as were questions concerning the purposes and preliminary findings of the research.

ANALYSIS AND DISCUSSION: INTERVIEW 2

As mentioned, the four problems that constitute Interview 2 were designed specifically to determine whether the responses of outcome-oriented subjects to a novel set of questions could be predicted. To test these predictions, scores based on performance in Interview 2 were correlated with an outcome score that summarized subjects' performance in Interview 1. Outcome scores were generated for each subject by summing their individual feature scores as described in the analysis of the reliability of features in Interview 1. Outcome scores had a possible range of from 0 to 17, with higher scores being indicative of an outcome orientation. For the 12 subjects who were

interviewed on the second occasion, outcome scores ranged from 0 to 15, with a mean of 6.83 and standard deviation of 4.39.

Scores for Interview 2 were generated by having two raters independently code each interview. The raters were myself and a graduate student who was blind to both the nature of Interview 1 and the hypotheses being tested.

In this section, each problem and the associated predictions will be discussed in turn. After specifying the predictions that were made prior to conducting the interviews, coding and scoring procedures will be described, correlations between performance in Interviews 1 and 2 will be reported, and then selected excerpts from the interviews that pertain to the predictions will be presented.

Cab Problem

The Cab problem (originally used by Kahneman and Tversky, 1972) has been used to study subjects' reluctance to take into account base rates (in this case the relative number of the two colors of cabs) in the formulation of probability estimates. Well, Pollatsek and Konold (1983) conducted interviews with 24 subjects using the Cab problem. They reported that several subjects believed that they were not being asked the probability that the errant cab was blue, but whether or not, in fact, it was blue. In addition, numeric answers that subjects were asked to provide in many cases seemed to be confidence ratings that their answers were correct, in that the values were only loosely based on the numbers given in the problem. These observations are similar to subjects' statements in the Bone and Weather problems from which the decision and single-trial features of the outcome approach were inferred. In questions involving uncertainty, subjects see their goal as arriving at a decision of what will or did occur on a particular occasion.

Given that the outcome approach describes a general orientation to uncertainty, those subjects who reponded in an outcome-oriented fashion in Interview 1 should respond in a similar way to the Cab problem. Specifically, it was predicted that outcome-oriented subjects, as defined by higher outcome scores in Interview 1, would be more likely to:

1) ask whether a number was required in answering the question of the probability that it was a blue cab;

2) encode the question, "What is the probability..." into the question, "What color was the cab?" (this recoding being indicated by responses to the effect, "I think the cab was blue"); and

3) base a numeric answer on a "loose" or qualitative interpretation of the evidence they thought relevant.

Performance of subjects on the Cab problem is summarized in Table 4. In accord with the findings of previous research, the modal response to the Cab problem was 80%. Subjects who gave 80% as the answer generally expressed the belief that the information concerning the base rates of green and blue cabs was irrelevant and should therefore not figure into the answer. Two subjects (6 and 8) argued that both the witness and base-rate information should be considered and gave

estimates of the probability that were intermediate between the 15% and 80% (.60 in both cases). These results are in basic agreement with those reported by Well et al.

Insert Table 4 about here

Performance of subjects with respect to the three predictions is also summarized in Table 4. Interrater reliability for coding these three categories was estimated by correlating the set of ratings of the two coders, with r = .759. The scoring rule applied was that both coders had to agree that a particular statement had been made in order for it to be counted. Scores on the Cab problem were obtained by assigning 1 point for each of the three categories checked, and summing across categories for each subject. Thus the scores could range from 0 to 3. These scores were correlated with the outcome scores (as indicated in Table 4) with r = .612, p<.025 (one-tailed). Considering the moderate level of interrater reliability, the magnitude of the correlation coefficient provides further evidence that the tendency to make yes or no decisions concerning the outcome of a single trial is a general approach to uncertainty observed over a variety of problems. An examination of the content of the interviews on the Cab problem (examples of which are included below) provides additional evidence that several of the subjects' responses were consistent with the outcome approach.

Given that the goal of the outcome approach is to determine what will or did occur, the question of probability is translated into the question, "What happened?" as indicated in the following response:

> S1: So you want to know if I think that's right--if it was blue. Well, I would say that it would be blue rather than green--just the fact that this really isn't important--the 85% are green, 15% are blue. I mean there are still a substantial amount of blue cabs out there. But the fact that the guy said--well, the court said that "in 80% of the cases you identified the right color." And the guy said he saw blue. He doesn't say, "I think I saw blue." He says, "I saw blue." So I would go with blue.

Given that the Cab problem asks specifically for the probability that the cab was blue, a subject's query of whether a number is required is indicative of the decision feature. When subjects asked if a number was wanted, I hesitated in order to allow them to clarify the question, and then if they did not continue, I asked what the alternative was to giving a number:

> S11: Let's see. Am I looking for a number as opposed to like--Am I looking to say "it's 80% probability that it was a blue rather than green?" Is that what I'm--
>
> I: What's the other option? How else would you prefer to give that?
>
> S11: "Sure, it could have been a blue cab." No--just that it would have been a strong--it was more likely as opposed to less likely. Kind of like this fit in. More positive as opposed to a definite number positive.

Central to the goal of specifying what happened is the single-trial feature, according to which questions of uncertainty are viewed as pertaining to a particular event as opposed to a set of events. Subject 5 justified ignoring the base-rate information on the grounds that at issue was the occurrence of a particular event, and that information

regarding a class of events was irrelevant:

> S5: It really doesn't matter how many cabs there are in the city. What you're thinking about is this one particular cab, whether it was blue or green. And since the guy was usually right--he's probably right.

As indicated above, the witness identification can be seen as applying to the individual event (the color of the errant cab) in a way that the base-rate information cannot. Using the base rates would seem to require regarding this particular accident as one of a set of accidents involving the two cab companies. To the outcome-oriented individual, this is not relevant to the question. What matters is this particular accident. It is evident in the above and following excerpts that the witness identification is not viewed as one of a class of similar identifications. Rather, the test situation may allow the outcome-oriented individual to assign the attribute "pretty reliable" to the witness and thus to the witness' identification of the color of the errant cab. It may be in the process of assigning this attribute that subjects "let go" of the specific meaning of the 80% and then give a confidence value for their belief that the cab was blue which is only loosely based on the 80% estimate of the witness's accuracy.

> S6: And since his visibility was pretty clear, and just on that--I'm not even taking these numbers so much as just, you know, conceptualizing it. Since he saw it was blue and there's more of a chance that he's right as seeing it as blue, that he saw it correctly. So I'll say that.

> S3: 80% just because he had--his percentage correct before was 80%, so it makes sense that he, probably--chance 80% that he got it right this time.

I: OK.

S3: Maybe better.

I: Can you explain why you think it might be better than that?

S3: Well, because more than not he got them right when they tested him before. So that's why it would be possible that he'd be more than 80%.

S13: Yeah--that he did guess, more than he didn't, the right colors. So I'd go with the blue. I'd say that it was a blue one.
[The coders disagreed as to whether this was an instance of a qualitative response.]

I: And how about just an estimate of what the probability would be, or a guess.

S13: I want to say just 80....

I: Is that 80 based on this [points to 80% witness accuracy]?

S13: No. I'm just trying to find--I'm just trying to think of something that's closer to 100--like over to more of a chance that it happened.

Bone-2 Problem

It was predicted that, given another opportunity to decide which side of the bone was most likely to land upright, outcome-oriented subjects would prefer to consider the physical features of the bone than frequency data. It was similarly predicted that, when asked how a statistician would determine the probabilities associated with each side of the bone, outcome-oriented subjects would believe that various physical features of the bone would be taken into account.

Subjects' performance on the Bone-2 problem is summarized in Table 5. Scores on the problem were obtained by scoring a) 2 points if subjects' first choice was not a frequency and 1 point if the second choice was not a frequency; b) 2 points if only physical properties were used in predicting ten trials, 1 point if used in conjunction with frequencies; c) 2 points if only physical properties were mentioned in the context of a statistician's method, 1 point if mentioned along with frequencies. Scores had a potential range of from 0 to 7. The interrater reliability on this problem was 100%. The correlation between scores on the Bone-2 problem and the outcome scores was $r = .788$, $p < .005$ (one-tailed).

Insert Table 5 about here

As predicted, outcome-oriented subjects were more likely to believe that a decision about the propensity of various sides of the bone to land upright should be arrived at by considering the physical features of the bone. One hypothesis as to why subjects prefer a physical to a statistical analysis is that the physical features of the bone might be viewed as a more stable source of evidence when compared to frequency data which can fluctuate from sample to sample. This seemed to be the rationale given by Subject 12 for basing predictions on an inspection of the bone. Asked why she thought the data from 100 rolls were unimportant, she replied,

S12: Well, because what they did may not be--it's sort of chance, you know, that happened. If the same 16 people did the same 100 rolls, it would probably be different the second time. It just doesn't seem a very specific kind of statistic.

I: And why do you think it would be different?

S12: Things change. I don't think anything duplicates itself exactly the second time.

I: How about the results I got in 1000 rolls?

S12: Yeah, that too is kind of iffy. If you did the same thing over again, plus a second 1000 rolls--I mean you could go on for 2000 rolls or whatever, and I don't know if it really would tell you much. Then again, I could be wrong.

A second hypothesis as to why a physical analysis might be preferred is that physical properties may be viewed as causal agents of what one wants to predict, while frequency information is not. Interview 1 provided no compelling evidence that this is the case; nor did Interview 2. One subject did feel that the physical properties were "real evidence" in contrast to frequency data. Asked to explain how she decided that D was the most likely side she responded,

> S3: Well, just 'cause it's flatter on the underside, so it's more likely to land on that side than it would on any other place.
>
> I: Are you using this information at all [the results on her last ten rolls]?
>
> S3: Maybe a little, yeah. I suppose. Well, I looked first and thought that was reasonable. So--

Asked how a statistician would determine the probability, she first mentioned surface area. Asked if they would use anything else, she said,

> S3: Well, they would probably make rolls themselves and see how it comes up. But I don't know if they would use that for real evidence or whatever.

> I: You feel like the results of what you got isn't real evidence?
>
> S3: Well, yeah. It has some. But there must be some, you know, like measuring the side, and that must be a little more precise than my rolls.

This subject's last statement suggests that she regards the properties of the bone as a more valid type of evidence because they are easier for her to think of as being measured precisely.

Subjects 5, 11, and 13, who also considered features of the bone to be important in a determination of probabilities, felt that they should be used in conjunction with, rather than to the exclusion of, frequency data:

> S5: ...I'd take number three [n=1000 data], and I'd look at each surface of the bone that had come up and compare it to the number of times it had gotten up and see why it had so I could decide whether or not the results were accurate, according to the shape of the bone.

In predicting ten rolls, Subject 5 inspected the bone carefully to decide how he would alot rolls to B and C since, according to him, they were so close in the frequency of past occurrence. His explanation of how a statistician would estimate probabilities was consistent with the approach he had employed:

> S5: ...a statistician would count a great deal of weight to the center of gravity and how it related, and, taking your results [n=1000 data], would come up with a bunch of statistics that would probably reflect fairly accurately your results, with perhaps some modification according to what he thought the structure of the bone gave out.

Subject 11 used only frequency data to make predictions about the bone, but felt that a statistician would, in a "joint effort," supplement these with an analysis of physical properties:

S11: 'Cause you'd roll the bone and get a rough idea of the probabilities, whatever they are--yeah, probabilites--and take it to have it analyzed to figure out if, structurally, you can understand why these--you know. You assign these particular values to each face, and then through comparing both, just--

I: But I might want to modify what I had got rolling it?

S11: Yeah. It's just kind of like added significance, or not significance--added sureness, or whatever--belief in your percentages.

In summary, the tendency to view physical properties of the bone as important in the determination of probabilites of the various landing orientations is strongly related to measures of the outcome approach. Physical properties appear to be regarded as information at least on a par with frequency data in making predictions.

That the first two predictions were verified is not surprising. What has been established is that subjects will respond consistently vis-à-vis the outcome approach on problems of the same type. The last two predictions are meant to serve a different purpose. They involve using the outcome approach to anticipate specific responses that had not yet been observed. Because of this, they provide more compelling evidence of the validity of the outcome approach.

Painted-die Problem

In the Painted-die problem, subjects were first presented a die and then six stones, both of which consisted of five elementary outcomes of

one type (black) and one of another (white). They were asked to predict whether in six trials they would be more likely to observe five blacks and one white, or six blacks. The answer according to formal probability theory is that the former is more likely, the probability of exactly five blacks being .402, the probability of six blacks being .335.

Most people, when asked, will respond that the probability of white being drawn is one out of six. But it is not clear what is meant by such an answer other than that there is only one white out of six sides. If people viewed "one out of six" consistent with formal probability theory they would expect to get, on the average, one white in six trials, which is also the modal outcome. Even failing this line of reasoning, one would predict on the basis of the "representativeness heuristic" (cf. Kahneman & Tversky, 1972) that people would believe five blacks to be the more likely outcome. According to the representativneness heuristic, since five black and one white looks more like, and in this case is identical to, the population distribution, it should be regarded as more likely (representative) than a sample that does not resemble the population as closely.

It was predicted that outcome-oriented subjects, however, would regard six blacks as the more likely outcome. In the outcome approach, the primary unit of analysis is the individual trial. Given a probability value, one way to arrive at a prediction of a trial is to decide which yes/no or I-don't-know decision point the probability value is closest to. Thus, rather than viewing the 5/6 as a value that relates to the expected relative frequency of blacks in randomly drawn samples, they would give it a qualitative interpretation of the approximate form "the next trial will almost certainly result in a black." When asked to predict the outcome for six trials, rather than using the 5/6 to form an expectation for the set of six trials, they should arrive at a prediction by summing over their expectations for each of the six trials. Since this expectation is more qualitative than quantitative in nature, it was expected that outcome-oriented subjects would more frequently say that six blacks are more likely, and that they would also believe that the ratio of blacks to white over a larger series of trials will remain above the normative value of five to one.

Interrater reliability for coding the Painted-die problem was 100%. Table 6 summarizes subjects' responses. Seven subjects felt that the outcome of six blacks was more likely in the case of the die, six subjects in the case of the stones. (Subject 13 regarded the two differently and changed her prediction to five blacks in the stone problem.) Scores for the Painted-die problem were obtained by giving 1 point if six blacks were expected in either the die or stone version; 1 point if fewer than 10 white were expected in 60 trials, or if more than six trials, on the average, were required to roll one white; and 1 point if the probability of a black on the first trial was estimated to be above 5/6 or 84%. The scores obtained in this manner were correlated with the outcome scores from Interview 1, with $r = .573$, $p < .05$ (one-tailed).

Insert Table 6 about here

Excerpts from the interviews indicate that, as suggested, subjects solved the problem by imagining a single trial for which the probability of black is overwhelming, and then extending this over trials to arrive at the conclusion that six blacks was the more likely outcome.

The responses of Subject 7 were characteristic of a frequency interpretation in Interview 1, and though he knows that the probability is 5/6 for a black, he still feels that six blacks are more likely and that ten or less whites would occur in 60 trials:

> S7: Well, I think it's--the white's there, but--I'm not exactly sure what I'm trying to say. Just because the odds are always the same. There's only one of them in there. So even though it's six rolls and there's six things in there, there's only one or the other that's going to come up each time. And that--chances are better than--five to one, one of the five blacks is going to come up.

Similar reasoning is demonstrated by Subject 15:

> S15: Because it's a higher probability of getting a black side because there are more black sides and so there's more probability that when you roll it, you're going to get a black side instead of that one white side.

Subject 3 combined the "more blacks" rationale with the reasoning that the sampling with replacement procedure does not guarantee white:

> S3: Probably more likely to get all black just cause--I don't know what percentage, but most of the die is black, so it's going to come up on that side. 'Cause you're not going to roll it on a different side each time you roll it, so that it's bound to come up one of those six rolls. So it probably would be black on all of them.

Subject 5 believed that rolling six dice at once would result in five blacks, but that rolling the same die six times would result in six blacks:

> S5: Well, each roll is a separate entity. You roll it, and a side will come out. Then you roll it, and a side will come out. You don't roll all six at one time. So likelihood is that each time it comes out, the side that has the dominate color, which is black, is the color that'll come out.

He finally rejected this reasoning, favoring five blacks in both cases. His initial response, however, provides a good example of what is being regarded as the outcome approach to this problem—that of imagining the results of one trial as almost certainly being black, and, by extending this qualitative judgment, concluding that six blacks are more likely over six trials. It is especially significant that this subject began thinking differently about the problem when he imagined all six trials occurring at once. (A similar belief in a difference between flipping one coin repeatedly or several at once was defended by the 18th century mathematician, D'Alembert. For an interesting account of this and other of D'Alembert's unconventional beliefs about probability, see Todhunter, 1949.)

Modelling Problem

The Modelling problem was designed to test some implications of the causal feature of the outcome approach. According to the outcome approach, frequency data are not considered to be as reliable a source in predicting outcomes as are phenomena that are causally related to the outcome. This being the case, it was predicted that outcome-oriented individuals would hold that if the causal features of a set-up were altered, outcome frequencies for that set-up would change accordingly. In the Modelling problem subjects were asked if it would be possible to construct an urn model of the bone that would produce results that could not be distinguished from results obtained from rolling the bone. They were introduced to the modelling concept in the Painted-die problem, where it was suggested that randomly sampling with replacement from six identically shaped stones would be the same as rolling a fair die. It was assumed that most subjects would accept this comparison since the most obvious physical feature—the symmetry of the six sides—was maintained. With an urn model of the bone, however, the important physical aspects of the bone—its irregularly-shaped sides and unequal distribution of weight—are transformed into unequal numbers of objects that are identical in weight and shape. It was predicted that outcome-oriented subjects, focusing on this difference, would expect that the data obtained from conducting trials on the two set-ups would be distinguishable in some way.

The results of the Modelling problem are summarized in Table 7. Subjects' performance on the modelling component of the Painted-die problem is also included. Scores for the Modelling problem were generated by assigning 1 point for each of the following four categories: a) if the urn model was not accepted in the case of the die; b) if a model for rolling the bone could not be generated by the subject; c) if the can filled with labeled stones corresponding in numbers to the statistician's estimates for each side was not accepted as a model of the bone, but the trial-by-trial method of filling the can was accepted, d) if it was believed that no model of the bone could be created. Scores on this problem could thus range from 0 to 4.

Interrater reliability for coding in these four categories was determined by correlating the two sets of ratings, with r = .93. The correlation between these scores and the outcome scores from Interview 1 was r = .610, p<.025 (one-tailed).

Insert Table 7 about here

The reasons given by subjects for rejecting the urn models are congruent with the hypothesis that they would do so because, in their analysis, important causal features could not be duplicated in the urn models.

Subjects 3 and 13 felt the urn model inappropriate in the Painted-die problem. They did not express concern over the corresponding features of the die and stone-filled urn per se, but over the differing sampling procedures in the two cases:

> S3: I think maybe the white side of the die would come w[illegible]e, just 'cause you don't have any control over that [makes an imaginary roll of the die]--Well, not that you do with the pieces, but--I don't know why. That's just what I think.
>
> S3: ....because you're putting your hand in there and taking out. I just, I don't know why, but I don't think you'd pick the white one as often as the white side of the die.
>
> S13: I just think grabbing something out--if you're grabbing it out, I think it would be more probable of being white. I don't know exactly why I'm thinking that way, but with this [die] I just [rolls die]--I don't know, tossing something just seems less of a chance, but picking something out seems more of a chance. You'd think it would be the other way around, though. But, I don't know....

In the following excerpts, subjects explain why an urn model is inappropriate in the case of the bone. The fact that the bone has six sides, uneven surfaces, and is rolled rather than picked out are all mentioned as important differences.

> S3: Probably be more likely to get no Es with the container full of 100 pieces. Just--well there is a slighter chance that it would come up, and there's six sides. So that's why I think it's more likely to come up on the bone.
>
> I: Because?
>
> S3: Because there's only six sides....
>
> S6: Probably it would be more likely to get no Es from the bone, 'cause the bone has to stand like that, and it would be easier just sitting in there—they don't have to—it's not like there's anything to do with the way it can stand and stuff like that.
>
> S6: ...[D] might be more likely from the bone. I don't really think you can say, but it just might be just because the Ds are all mixed up in the can, whereas in the bone, that's the easiest side for it to land on. That's the most--that's the way it stands easiest, so you might get it more times in a row in the bone.
>
> S7: ...you could easily pick 100 of them out without hitting an E. You'd have more trouble tossing the bone so you didn't come up with an E.
>
> I: And why is that again?
>
> S7: ...It just seems like because you're picking them out you could just miss one of the Es.
>
> S15: ...these stones and the die are uniform, and each side is the same--it's the same surface. And this [bone] is all different. So this will affect--the shape of the side will affect the way it's going to roll. Like it would be harder for it to stand up on E like that. So you'd have to

> replicate the little indents and stuff like--So you couldn't make a--you couldn't turn it into six stones or something like that.

The persistance demonstrated by subjects in insisting that the bone could not be modelled was particularly impressive. The interview probes were designed to give subjects several opportunities to accept a model: They were given one alternative after another. The independent coder, not knowing the intention in this probing, discretely noted in two instances that the subjects had been strongly led to accept a model. The other subjects were as strongly "led" but insisted repeatedly that the model suggested would not be comparable to rolling the bone. Attending to the physical features as opposed to the resultant frequency data of a chance set-up appears to be a deeply ingrained orientation.

GENERAL DISCUSSION

Behavior inconsistent with formal probability theory has usually been described as irrational (Cohen, 1981, notwithstanding). In this study, the basis for an alternative description was sought--a description according to which such behavior could be viewed as coherent within the context of some theoretical framework. Such a framework was inferred from an initial set of interviews and was described as an outcome-oriented approach to uncertainty. In a second set of interviews with the same subjects, the outcome approach was used to successfully predict performance on a different set of problems.

The primary goal of the outcome approach is to predict the outcome in an uncertain situation. When required, outcome-oriented individuals will provide values which gauge their confidence in the prediction. In this respect, the outcome approach is similar to a personalist theory in that probability is a measure of degree of belief. However, there are at least two major differences between the two perspectives. First, personalist theories were motivated by the desire to put subjective probabilities on a rational and scientific basis. Thus, among other requirements in these systems, subjective probabilities of repeated events should, over a long series of observed trials, closely approximate the actual frequencies of occurrence:

> If a person assesses the probability of a proposition being true as .7 and later finds that the proposition is false, that in itself does not invalidate the assessment. However, if a judge assigns .7 to 10,000 independent propositions, only 25 of which subsequently are found to be true, there is something wrong with the assessment.... The attribute that they lack is called calibration.... Formally, a judge is well calibrated if, over the long run, for all propositions assigned a given probability, the proportion of true equals the probability assigned. (Lichtenstein, Fischhoff, & Phillips, 1981, p. 2)

The outcome-oriented individual appears uninterested in calibration as defined above. (See, for Example, Excerpt 4 of Interview 1.) Rather, interest is focused on whether or not, on a particular occasion, a correct prediction can be made. If a prediction turns out to be incorrect, the prediction was wrong and the confidence value, if assigned, was erroneous.

The other, and related, difference between the outcome and personalist approachs is the method by which frequency data are translated into a confidence value. Since a goal in a personalist theory is to be well-calibrated, frequency of past occurrence of some event is interpreted directly as a confidence in the future occurrence of the event, all other things being constant. (Applying Bayes' Theorem to refine subjective probabilities is one algorithm that guarantees good calibration.) In the outcome approach, frequency data are not directly used to formulate a probability. It is especially clear in the Cab, Painted-die, and Bone problems that frequency information is first translated into a more qualitative belief from which a numeric confidence is subsequeptly generated if necessary. A similar two-stage process of generating subjective probabilites has been suggested by Adams and Adams (1961) and more recently by Koriat, Lichtenstein and Fischhoff (1980).

> To assess one's confidence in the truth of a statement, one first arrives at a confidence judgment based on internal cues or "feelings of doubt".... The judgment is then transformed into a quantitative expression, such as a probability that the statement is correct. (Koriat et al., p. 108)

It should be added that the step of transforming internal cues into numeric values is probably not an essential component of the outcome approach outside the laboratory. It seems to be done, and often begrudgingly, only if a request for a percentage or probability is made. In the outcome approach, discriminating between small differences in the strength of these inner feelings is unnecessary. Given the goal of predicting the most likely outcome on a particular occasion, one only need be aware of which outcome is associated with the strongest inner feeling. In this respect, it has been argued that people are well-prepared for the majority of decisions they face from day to day (Fhaner, 1977). When a decision must be made, not only are frequency data seldomly available, but in many of the situations we face, frequency data would be of limited and questionable value. It is difficult to imagine, for example, what frequency data one might want in trying to make a decision about marriage, or of whether or not to start building a bomb shelter.

There are many decisions, however, in which frequency data could be of considerable help--Which car to buy, which college to attend, which lawyer to hire, which judge to hope for and which jury to select. Considering the physical or mental space which would be required so that relevant data could be held readily available, one possible explanation of people's behavior in such situations is that they apply judgment heuristics that obviate the task of data collection and analysis. According to this "heuristic hypothesis," it is possible that at some more basic level, people reason in accord with formal probability theory, but to save time, heuristics are usually, and consciously, employed.

However, the results of this investigation do not support the conclusion that subjects are employing judgment heuristics in so far as the term implies a conscious application of short-cut procedures. When given data in the Bone problems that required no summarizing, subjects still appeared to translate the data into more qualitative judgments from which numeric values were derived. Futhermore, in the case of the Painted-die problem, this qualitative-to-quantitative processing led to a prediction that was inconsistent with what one would expect on the basis of the representativeness heuristic.

In the outcome approach, the transformation of frequency data into beliefs appears not to be accomplished via judgment heuristics a la Kahneman and Tversky, but through causal analysis and theory construction. That is, the outcome-oriented individual contructs theories about the phenomena under consideration that are useful as a basis of not only prediction but, perhaps more importantly, explanation. If the outcome approach is a valid description of the novice's orientation to uncertainty, then this desire to apply a causal rather than a black-box model to uncertainty is the most profound difference between the novice and the expert of probability. The observation that causality is important in people's judgments of uncertainty is not new (e.g. Azjen, 1977; Tversky & Kahneman, 1980; Rosenhan, 1973; Walster, 1962). What this study suggests is that the tendency to apply causal models to probabilistic situations should be viewed as one component of a more general orientation to uncertainty. Whether or not this interpretation can inspire further research that more clearly documents and explicates the use and nature of causal reasoning under uncertainty will be the more critical test of the validity of the outcome approach.

Footnote

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TABLE 1

SUBJECT BACKGROUND INFORMATION

Subject Number	Sex	Major	College Math & Statistics (Interview 1)	College Math & Statistics (Interview 2)
1	M	Psych	H.S. STAT	Intro STAT*
2	M	Psych	H.S. STAT	Intro STAT*
3	F	Psych	precalculus*	
4	M	Forestry	calculus Intro STAT	
5	M	Comm. Disorders		
6	F	Psych	precalculus*	Intro STAT*
7	M	Psych		precalculus*
8	F	Psych	precalculus Intro STAT	
9	F	Psych		
10	F	Psych	precalculus	
11	M	Psych	precalculus	
12	F	Elem. Ed.		
13	F	Pub. Relations		
14	F	Psych	Intro STAT*	
15	F	Psych	precalculus Business STAT	
16	F	Psych	Intro STAT	

*Currently enrolled

EVALUATIVE RESPONSES AND YES/NO PREDICTIONS ON THE BONE AND WEATHER PROBLEMS

	Evaluative Response			Yes/No Predictions		
	Bone	Weather		Weather		
S#	I was right (wrong)	Forecaster was wrong	7/10 = pretty accurate	Compare value to 50/100%	Qualitative interpretation of 70%	50% = anything can happen
1	x			x		
2						
3	x	x	x	x		
4			C*			
5	x		C	x	x	
6			x	x		
7						
8			C	x		x
9	x	x	x	x		x
10	x		x			
11	x	x	C			
12	x	x	x	x	x	
13	x	x	x	x	x	
14			x	x		x
15		x	x	x	x	
16	x		x	x		

*C indicates conflict between "pretty accurate" and "perfect."

TABLE 3

CAUSAL-FEATURE RESPONSES ON THE WEATHER, BONE, AND MISFORTUNE PROBLEMS

	Weather		Bone				Misfortune			
Subject No.	70% = measure of causes	Error due to variability of weather	More trials of questionable help	Ignore 1000 data in predicting 10 trials	Predictions based on physical features	The roll makes a difference	No mention of chance	External-controlling force	Internal-causal connection	Subject No.
1										1
2										2
3	x			x		x	x	x		3
4										4
5	x					x			x	5
6			x		x					6
7								x	x	7
8		x				x				8
9	x	x	x		x	x			x	9
10			x							10
11			x			x	x	x	x	11
12	x	x	x	x	x	x		x	x	12
13				x		x	x	x		13
14									x	14
15						x				15
16										16

TABLE 4

RESPONSES TO THE CAB PROBLEM

Subject No.	Outcome score	Probability Estimate	Outcome-oriented Responses: Asked if number wanted	Qualitative response	Estimate based loosely on data
1	1	.80	x	x	
2	0	.80			
3	12	.90-.95			x
5	8	.80	x		
6	5	.80-.85			
7	1	.80			
8	5	.80-.90			
11	9	.85-.90	x		
12	15	.70		x	x
13	12	.90	x		x
15	7	.85	x	x	
16	5	.80			

TABLE 5

RESPONSES TO THE BONE-2 PROBLEM

Subject No.	Outcome score	Desired Information: Surface area	Desired Information: 100 trials	Desired Information: 1000 trials	Desired Information: Center of gravity	Desired Information: Bone to look at	Desired Information: Ss' last 10 trials	Basis of Prediction: Frequencies	Basis of Prediction: Physical Properties	Statistician's Estimates: Frequencies	Statistician's Estimates: Physical Properties
1	3		2*	1				x		x	
2	0		2	1				x		x	
3	12					2	1	x	x		x
5	8			1		2		x	x	x	x
6	5		2	1				x		x	
7	1			1		2		x		x	
8	5		2	1				x		x	
11	9		2	1				x		x	x
12	15	2				1			x	x	x
13	12		2	1				x		x	x
15	7			1		2		x		x	x
16	5		2	1				x		x	

*1 indicates 1st choice; 2, 2nd choice.

TABLE 7

RESPONSES TO THE MODELLING PROBLEM

Subject No.	Outcome score	Die: Stones not model of die	Bone: Model not spontaneously developed	Bone: Rejected urn-model based on statisticians' estimates	Bone: No model possible
1	3				
2	0				
3	12	x	x	x	x
5	8				
6	5		x	x	x
7	1		x	x	
8	5				
11	9				
12	15		x	x	
13	12	x	x	x	x
15	7		x	x	
16	5				

TABLE 6

RESPONSES TO THE PAINTED-DIE PROBLEM

Subject No.	Outcome score	Expected No. of White: In six trials	Expected No. of White: In sixty trials	Expected No. of White: Average trials to get white	Predictions and Probabilities of Each Trial (Outcome of trial in parentheses): Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
1	3	1	10		5/6B (W)	· (B)*	· (B)	· [illegible]	· [illegible]	· (B)
2	0	1	10		5/6B (B)	· (B)	· (B)	· [illegible]	· (B)	· [illegible]
3	12	0		6-7	.90-.95B (B)	· (B)	.85-.90B (B)	.80B [illegible]	.93B [illegible]	· (B)
5	8	1	10		5/6B (W)	(B)	· (W)	· (B)	· [illegible]	· [illegible]
6	5	1	10-12		1/6B (B)	· [illegible]	1/6W (W)	1/2 [illegible]	1/2 (B)	1/2 (B)
7	1	0	<10-10		5/6B (B)	· (B)	· (B)	· (B)	· [illegible]	· [illegible]
8	5	1	10		.80B (B)	· (B)	· (B)	· (B)	· [illegible]	· [illegible]
11	9	0	10		5/6B (B)	· (B)	· (B)	· (B)	· [illegible]	· (B)
12	15	0	4		.90B (B)	· (B)	· (W)	· [illegible]	· [illegible]	· [illegible]
13	12	1*		10	.90B (B)	· (B)	· (B)	.20 (B)	[illegible]	· [illegible]
15	7	0	5		.95B (B)	· (B)	· (B)	· (B)	· (B)	· (B)
16	5	0		12	5/6B (B)	· (B)	· (B)	· (B)	· [illegible]	· (B)

*½ for stones; 0 for die.

*dot indicates same prediction as previous trial.

A "Cultural" Look at Physics Students and Physics Classrooms

An Example of Anthropological Work in Science Education

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1 - Introduction

The following paper presents some recent work which suggests that science education research might profit from an examination of social and environmental aspects of students and the classroom. It is somewhat speculative, and some of the ideas it advances are embryonic; nevertheless, it does have an empirical basis. My goal is not to end a discussion on what should or should not be done in the future, but rather to start one.

In this work, I have adopted an anthropological approach in examining the relationship of between physics students, physics classrooms, and physics subject material. One reason is that I have noted that science teachers often speak of their students "being in a different world" and students saying that science or mathematics is "a foreign language to me." Assuming that the use of these cultural metaphors is not accidental, an anthropological approach to studying this interaction may be fruitful.

A second, more important, reason is that the education researcher has a relationship with his/her subjects that is in certain important ways similar to that of the anthropologist investigating a foreign culture. Indeed, a point too often overlooked in cognitive education research is that the situation in which students learn the subject material of mathematics or physics is most often a classroom with a teacher, and this situation is if nothing else involves a social setting.

In particular, much "purely cognitive" research has documented the existence of a strong and resilient mismatch between naive and expert theories of nature. These studies have often recommended "direct remediation" in the form of exercises which force the student to confront explicitly his mistaken or ambiguous ideas.[1] However, they have not established that direct remediation is an optimal pedagogical approach of choice. Research which goes beyond purely cognitive factors may suggest mistaken theories of nature are only one part of a gestalt which science teachers must change if they are to be successful.

The primary goal of this research is not detailed prediction about difficulties which students encounter or what a given student may do, or what specific fixes for student difficulties will work. Indeed, it abandons the attempt to construct a causal and deterministic theory, in which a certain set of variables can be shown to be uniquely responsible for a certain set of outcomes. Rather, it seeks to describe a constellation of influences, a gestalt, a mind-set, which facilitates (but is not necessarily directly responsible for) the observed outcomes. In doing so, it tries to transmit to the reader insight, intuition and experience.

The research I will describe thus has some of the tone and flavor of political science, psychiatry, history, or social work - all professions in which the normative research situation is one in which there are multiple causal factors and mutually dependent and highly interactive influences which are affected by the external environment as well as individual circumstances and history, and which depend on the effectiveness of the behavior which they nominally determine.[2]

2 - Physics Students, Physics Classrooms, Physics Material

The work I will describe began at M.I.T., and continued at the University of Washington. It is still in progress, so this paper should be taken as a progress report rather than as a final project report.

2.1 - General Perspective - Gross Evidence

In my doctoral thesis work at M.I.T., I examined some of the difficulties that beginning physics students encountered in solving physics problems. As part of this work, I also tried to develop specific remedies for these difficulties; my solution was a seminar in which I would teach problem solving techniques explicitly.[3] I found that after a semester or so, my students were able to carry out properly most of the techniques that I had taught them, but I found out that despite their apparent competence with these techniques and higher rate of success at problem solving when they in fact used these techniques, most students did not use them.

Of course, this was rather disturbing to me. I attempted to find out why they did not use these techniques in their actual work when most had described these techniques as helpful in seminar evaluations. I discovered two primary reasons. One reason was that the existence of partial credit and other academic pressures led them to expend their energies elsewhere (Lin, 1982). The second reason was that despite their success at using them, they did not believe in their efficacy. It is the sources of this disbelief that I want to explore now.

First, note the empirical fact that introductory physics courses are essentially the same all over the country. A small liberal arts college in the rural Midwest covers roughly the same material in the same amount of time that a large urban university in Boston covers. To first approximation, the problem sets are the same; the examinations are the same; the labs are the same.

More importantly, their goals (as reflected by the common curriculum) are the same. In particular, beginning courses

- teach the student how to use the analytical tools of the physicist: deduction from first principles, notions of approximation and modeling, mathematical representations of physical reality. In doing so, they
- emphasize problem-solving of a particular type. The problems in question are soluble, have well-defined right answers, usually contain exactly the information needed to solve the problem. Consequently, problems and experiments of the standard course
- are confined to areas in which current knowledge is strong and relatively certain, and whose answers can be evaluated with very little dispute. Answers and paths to those answers which closely approximate those of the expert are considered good; therefore, it is not unreasonable to assume that beginning courses

- seek to make the student more like the teacher along certain characteristic dimensions - in particular, with respect to problem-solving techniques. To the extent that a student learns to reproduce independently the problem solutions that the teacher can produce, then to that extent the student deserves high grades and the course is a success.

This uniformity of introductory courses is consistent with two hypotheses. One hypothesis is that uniformity would be expected in courses in which there are "objective" standards: such courses might include those in physics, mathematics, engineering.

This hypothesis does have a certain appeal (especially to physicists, mathematicians, and engineers), but there is at least one other hypothesis consistent with this uniformity. In particular, one would also expect uniformity if the introductory course were a kind of socialization process, an initiation rite for students about to enter a different world, namely the world of the physicist.

To help decide between these hypotheses, consider the fact that there are significant differences between physics and physics courses. In physics, the ultimate judge of the researcher is nature. In a physics course, the ultimate judge of the student is not nature but rather the teacher, laboratory experiments and lecture demonstrations not withstanding. Theoretical calculations (i.e., problem sets and exams) are checked by reference to authority (i.e., instructors), not by reference to experiment. In laboratories, students strive for "good" results, where "good" is defined by closeness to accepted values: when a student measurement does not conform to accepted values (within appropriate error bars), the usual lab instructor reaction is that the student made an error in his measurement.

Therefore, it is at least plausible that the enterprise facing the student is not the same as the enterprise facing the research physicist. Additional evidence for this position comes from the fact that certain activities characteristic of research physics do not appear on the list of introductory course goals; introductory courses do not ask students to design experiments, formulate problems, guess relationships, or develop theories, although analogous demands are often placed on beginning students in other "more subjective" subject areas.

The socialization hypothesis also implies the existence of a human (and therefore somewhat arbitrary) dimension to judgments made in the world of physics courses, and it is not inconceivable that non-objective factors might influence the learning of ostensibly objective material. Thus, I will spend the rest of this paper exploring the socialization hypothesis.

In particular, I will ask "How does the social context of the introductory physics course require its own ways of thinking, as distinct from ways of thinking useful outside the physics classroom?" An answer to this question might illuminate some of the difficulties that students encounter in their physics courses. I recognize that it may be controversial, but I offer it simply as a different perspective on the process of science education, which after all does take place mostly in classrooms.

The purpose of formal classroom education is to transmit to students knowledge and thought processes which are useful to them in interpreting their experience (broadly construed), in making decisions, or in becoming proficient with desirable forms of behavior. This is also an reasonable approximation to the definition of the term "culture" used by cognitive anthropologists studying different societies (cf., Spradley (1972)), and therefore it suggests a cultural metaphor might shed light on the situation.

Of course, detailed correspondences derived from metaphors are never guaranteed, and the validity of individual correspondences must be supported on a case-by-case basis. For my purposes, the only correspondence of interest is that different cultures have different ways of organizing and understanding the world, just physics students and physics teachers have different ways of looking at the subject called physics.

With this in mind, let me first present some evidence that there is indeed a difference in the mental cultures of students and teachers. One piece of evidence is provided by comments which most physics teachers have heard at one time or another. Many students have uttered comments to the effect that "physics is like a foreign language to me"; many teachers have often commented that "students seem like they're in a different world." Such metaphors indicate a certain alienation of student for subject material, quite independent of individual personality clashes.

A second type of evidence is found in the transcript excerpts below. These transcripts were taken from interviews with students at the

University of Washington in which the primary purpose of the interview was to elicit student predictions about the behavior of a demonstration in which objects came under the influence of external forces. These excerpts emerged from conversation after the primary questions were asked.

Transcript 1

S: I have the attitude that I should just believe what they [physics teachers] tell me.

I: It seems like you're saying that your everyday life experience doesn't help; it [the demonstration] doesn't at all do what physics tells you it should do.

S: Yeah..., because the things I see in physics are completely different than what I would normally expect them to be... Even though I've seen it in lab, I say "OK, I'm just going to pretend it's true", and I work the problems like that... I don't believe what I'm seeing. I think if I took more classes, and I saw it more often, I wouldn't have to play that game, where I pretend that's right. But that's what I do right now... It [the game] seems like there are these strange and crazy things going on out there, things that don't make any sense.

Transcript 2

S: My intuition for physics and the way things work isn't always the way I'm told they're supposed to work. I can see how the major concepts work, but when it comes to actually doing problems, when I try to intuitively work the problems, it just doesn't follow... Whatever they tell us, that's what I'm going to say, because I don't really understand it... I read the text, but I don't really understand, because the book and the professors assume you know some of the basic rules of the game already... It's like learning to play chess by watching people play, when nobody tells you the knight moves in an L... I'd have to sit there and figure these things out myself and it might take a year.

Transcript 3

I: [Student has been asked what are the forces acting on a frictionless puck moving on a frictionless table after a push.]

S: The initial push, the force of gravity, and the table up.

I: How do you know?

S: Well, I know there's gravity, and there's got to be the force from the table, ..., and now I'm not so sure if the initial push is a force still... yeah, I think so.

I: You think so, what?

S: There's the force of the initial push, but when things are falling off the sides of roofs and you draw the free-body diagram, in mid-air you just have gravity going down, and that's it, so...

I: So now you have a conflict.

S: I have a conflict now.

I: How are you going to resolve your conflict?

S: I'm going to remember the mistakes I've made before, and take things that I had in physics class... like things I've gotten right even when I was sure it was the opposite... like the thing falling off the roof, when we drew the free-body diagram in mid-air, I really wanted to put a force pushing sideways, but he told us in class there was only gravity, so that's what I put, and I got it right. I still look at it like I'm following the rules of the game.

I: How come? Do you have your own rules?

S: Well, if there's an effect from something, then I want to put that in as a force. I mean, the effect is still there.

These students seem to be responding to a very strong sense that physics - or at least the physics they are getting in their courses - is foreign. S1 mentions "strange and crazy" things going on; substituting the words "arbitrary and random" doesn't seem to change the spirit of the student's utterance. S2 draws an analogy between learning physics and learning chess, an obviously human activity in which the rules are arbitrary. S3 resolves a conflict by a "brute-force" remembering of something he has been told but does not believe.

Their descriptions of physics as a game to be played, and their sense that the rules are arbitrary, present a rather potent challenge to the notion that physics teachers are teaching something about something endowed with unquestionable objectivity. Indeed, to the extent that a global difference in perspective does exist, one might also expect to find more specific manifestations of this difference in perspective. It is a description of some specific differences that is the subject of the next section.

2.2 - Specific Examples of Differences

More specifically, here are some transcripts which illustrate that students do indeed perceive differences between the mental culture to which they are accustomed and the mental culture which they must adopt in order to survive in a physics class. In particular, the transcripts below illustrate a certain discomfort and unfamiliarity with the type of analysis that characterizes the standard introductory course.

Transcript 4

S: It seems that physics has a different way of looking at things, where you take apart everything, and it's just... it seems separate from real life.

I: How is it different?

S: It's the taking apart everything and explaining every little, every motion, every force that acts on something. If I hadn't taken physics, I wouldn't have thought about it that way. ...[In physics,] I just have to try to learn the way physics looks at things.

This student appears to view the analytical process of decomposition into component parts as foreign to his way of thinking.

Transcript 5

S: I'm never really sure about a problem. I can get my reasoning turned around sometimes. I look at it the wrong way, and I think there's different things acting on it and I screw up... [or] sometimes I don't take everything into consideration. Physics is teaching me to look at things in a different way. Before, I never thought of the table as pushing back up on my hand. And it also teaches me to look at all the different things that could be going on with this particular object. Most of my problems come when I don't consider everything.

This student notes the variety of things that might happen, and explicitly comments on learning to look at familiar things in new ways. He also attributes to this newness some of his difficulties in learning physics.

Transcript 6

S: My experience tells me certain things, which gets me confused. When I just think physics, I get what I should get, but when I start using my experiences, I'm never sure what will happen, because sometimes it does one thing, sometimes another. If I use my first reaction, I'll get one answer. If I ask "Why?", though, I'll get another, because you start tracing it through and you realize there's no good reason for your answer.

This student realizes (but is uncomfortable with) the need for drawing conclusions based on some kind of argument.

Additional examples will follow later, but for now, it is important to note that these transcripts all make reference to new ways of thinking about the world. In addition, I find that these expressions of unease are relatively common.

The first specific difference I want to illustrate concern the difficulties can arise when the practices of everyday discourse are used within the context of physics classes. The transcripts below illustrate.

Transcript 7

[The problem in question is a standard textbook problem in which two masses are present.]

S: I want to use $F=ma$ on this problem.

I: OK, that's right. How can you use it?

S: Well, I'm not sure.

I: What do the F, the m, and the a mean?

S: F is force, m is mass, a is acceleration.

I: The F=ma applies to _something_, doesn't it?

S: Sure. It applies to the problem.

I: Can you apply F=ma to some particular object in the problem?

S: What do you mean?

I: The m in F=ma stands for some particular mass when you apply it in working a particular problem.

S: I still don't understand.

Transcript 8 (Data courtesy Ron Lawson)

I: What do you think of when you say the word "momentum"?

S: I think of force, movement, you know, like the force behind it.

I: How is the concept of momentum related to this situation, a puck sliding on the table at steady speed?

S: It's the force or the speed that's keeping it going.

I: What about the word "force"? What do you think of there?

S: I think of energy, something like the energy to move it. Force that is producing an action.

I: What are the forces on the puck when it's moving on the table with a steady speed?

S: The initial momentum that you use, the initial pushing is just continued out; it is just carrying out that force.

Transcript 9 (Data courtesy Ron Lawson)

I: What does force mean?

S: A force is present when an object changes speed, direction, stops, or starts.

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I: What are the forces acting on the puck when it is moving north?

[The situation is one in which a frictionless puck is set in straight-line motion (north), and the student is asked to deflect it (to the north-east) using an air hose.]

S: Its mass and speed. At the intersection [when the air hose is applied] , the forces are speed, mass, and the push. When it's going NE, the [illegible] mass and speed.

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[Interview proceeds to different topic, returns to same topic 10 minutes later.]

I: What are the forces when it's going NE?

S: The speed is acting NE, and the mass is acting down... Actually, I don't know if you can talk about speed as a force that way.

I: How so?

S: I guess, speed isn't a force, it's a measure of distance and time. It may reflect another force, but I don't think speed is the actual force.

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interview proceeds to a puck in circular motion.

I: What are the forces on the puck?

S: The mass, acting down; the pull [of the string] towards the center, and the speed straight ahead.

Transcript 7 portrays a student who does not see the need to bind the variables in the general relation to the specifics of the problem.

Transcript 8 illustrates a student who does not see a need for differentiating between different technical terms; energy, force, momentum all seem to mean roughly the same thing - motion.

Transcript 9 illustrates how the student does not make use of the definition of "force" which she indicated she knew at the beginning of the interview. Her initial definition is quite adequate, and yet her later use of the term is not entirely consistent with her definition.

Generalizing from these three transcripts, I would argue that they illustrate certain differences in the structure of discourse in everyday life and in physics classrooms. In everyday discourse, one primary goal (possibly the primary goal) is to communicate ideas and transmit knowledge; this process depends crucially on the existence of a shared context and understanding. I can understand what another individual says largely because I share with him a background which enables me to identify with minimal cues the referent of his words, and thus extensive specification of terms and refinement of definitions are unnecessary. In other words, everyday discourse proceeds on the expectation that "the parties involved will in fact understand each other with little

difficulty".[4]

By contrast, language in physics (and in physics classrooms) is used not only for transmission of information but also for defending an argument. The latter use of language arises from the physicist's faith that unreliable information is best eliminated through public criticism. Therefore, physics places one burden on the one setting forth the argument (e.g., the student solving the problem) to be explicit, and a second burden on the one challenging the argument (e.g., the teacher grading the problem) to be skeptical. In addition, physics specifies that differences and ambiguities are to be resolved through the use of "rules that define an adequate logical proof".[5]

This process is clearly visible in the grading of problems; "unclear", "Why?", and "This doesn't follow" are all very common remarks on graded homework and exams. Indeed, the grader insists that the student's solution conform (except for minor details) to one of a very few canonically correct solutions; the higher the degree of conformity, the higher the grade.

In skeptical/explicit discourse, a shared understanding cannot be taken for granted; any term with a potentially ambiguous meaning must be further specified. [In addition, the use of deductive first-principle solutions requires that variables must be bound to specific elements in the problem.] Thus, the discourse of physics classrooms will seek to eliminate (or at least minimize) ambiguous concepts, unbound variables, and informal definitions. It is this set of expectations that seems to underlie a typical physicist's reaction to Transcripts 7-9 above as illustrating student error.

A focused contrast between everyday discourse and skeptical/explicit discourse may be useful here. The (denotative) meaning of a word is its definition. In everyday life, definitions are implemented through the use of prototypical examples: with enough examples of a chair, one learns what does and does not count as a chair. However, the approach of the physicist to the definition of "chair" might go like this:

Transcript 10

P: What's the definition of a chair?

S: Well, that's a chair over there.

P: No, I want to know what a chair is.

S: Well, it's something with four legs, a seat, and a back.

P: What about the swivel chair that I'm sitting on now? It doesn't have four legs.

S: A chair is something with a seat elevated from the ground and a back.

P: Does a bean-bag chair count? They're listed in the Sears catalog under chairs.

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Transcript 11

S: I'm tired.

P: How do you know you're tired?

S: Huh? Well, I don't have much energy to do things today.

P: Why is that? And why today? Was yesterday any different?

S: I moved yesterday.

P: Why should that have made you tired?

S: I carried many things.

P: What was in them that made them so heavy?

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Obviously, these simulated transcripts could go on forever, to the frustration of S. Why would S be frustrated? I suggest it is because everyday discourse simply does not require the precision of expression (Transcript 10), or the skepticism (Transcript 11) to which physicists are accustomed; indeed, the demand for explicitness and the assumption of skepticism can lead to conflict when applied to everyday discourse.[6]

In contrast to these simulated transcripts, Transcript 9 depicts a student who initially provides a certain definition of "force", and proceeds to ignore this definition in subsequent dialogue. It sounds much like an everyday conversation, and it is this very casualness which would lead many physicists to criticize this student on the grounds that he is using the term "force" without sufficient precision.

A possible consequence of the skeptical/explicit form of discourse may be that students will perceive it as adversarial and hostile, even if no such intent is implied. Certainly, the hypothetical S in Transcripts 10 and 11 might react with hostility and anger. I have heard students complain about "being badgered" and "browbeaten". Conversely, good student work is very rarely original; rather, it mimics very well expert work. Thus, the student is in the unenviable position of receiving criticism for poor work, but little personal acknowledgement for good work.

Finally, it is useful to note that skeptical/explicit discourse is a mode in which justification is at issue. This contrasts strongly to a mode in which discovery is at issue (cf.,Hanson (1958)). A student usually looks for assistance in discovering a solution (especially when he can't do a certain problem), while a critical physicist operates in justification mode.[7]

For example, consider the following transcripts:

Transcript 12

S: All my life I've been taught that things go in certain ways, and then you get in physics and it doesn't work out quite that way, like today he had the things that roll uphill.

I: So that seems real weird to you.

S: Yeah. It just doesn't seem it would happen in real life, and then in physics, you see it happen, and it's like a magic show.

I: How is physics different than real life?

S: In real life, I don't think in terms of all this trig and other stuff, and when you look at a physics problem, you have to figure out where all the forces are going and all that. In real like, you just think "Well, if I throw the rock over there, it's going to go up and come down." In physics, you have to figure out why it does that.

This student is apparently uncomfortable with the counter-intuitive demonstrations that all physicists like to use. In addition, he comments that a difference between physics and the rest of life is the need in physics to answer "Why?" Here is a more specific transcript related to the same discomfort.

Transcript 13

A 40 kg slab rests on a frictionless floor. A [illegible] block rests on top of the slab. The coefficient of sta[illegible] friction between block and slab is 0.6, while the coefficient of kinetic friction is 0.4. A horizontal force of 100 Nt acts upon the block. What are the resulting accelerations of the block and slab?

The student has written the following as her complete solution to the problem:

$$F = ma$$
$$100\ N - (0.4)\ (10)\ (9.8) = (10)\ a$$
$$a = 6.1\ m/sec^2$$

I: How come you used kinetic friction here?

S: Well, it's moving, and kinetic means moving, so I used kinetic friction.

I: Let's say I move this book with my hand. Is the friction acting on the book static or kinetic?

S: Static.

I: Even if it's moving?

S: Yes.

I: How come?

S: Because your hand and the book are moving the same.

I: Right. Now. how do you know that the block and the slab are moving the same [or different]?

S: Well.... [long pause]

I: The point is that you have to make an *argument* for why the block will slip on the slab. The problem might be set up so that they didn't slip.

S: You mean you can't just *know* they'll slip?

The problem presented is non-trivial. However, what makes it non-trivial is that there is in fact no a priori reason for choosing kinetic over static friction; an explicit argument must be made for why one or the other is more appropriate. More generally, the physicist requires reasoning to be made explicit because only explicit reasoning can be criticized; tacit reasoning can never be challenged. Transcript 13 is illustrative of a student who apparently does not accept this requirement.

Another aspect of the mental culture of the introductory course is the emphasis on what I call "componential analysis" - the idea that a problem can be decomposed into smaller parts, each of which can be the subject of analysis which is useful in solving the original problem. For example, it may refer to a chain of causal relations in which the proximate cause of an event is considered worthy of analysis (and indeed is often considered the direct cause of the event):

Transcript 14

This student is the same one quoted in Transcript 12.]

I: Can you give an example of the difference between physics and real life?

S: I remember the friction force making the car go. I had a tough time with that. I think of the motor as doing the work. In real life, you think "You're putting gas into the motor, so the motor is doing the work; it's spinning the wheels, so the wheels must be pushing the car."

I: So that doesn't feel right to you.

S: Well, it's true, but in real life, it doesn't seem.... In real life, I guess you haven't thought about the problem long enough to come up with an answer. Sometimes it seems like physics is speaking a different language, like it says friction is moving the car, when you ought to be calling it the engine.

This example is familiar to most teachers; indeed, most have encountered in their teaching some resistance to this way of analyzing the causes of motion. Neverthless, the focus on proximate and local cause is characteristic of physics.

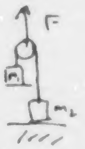
A second type of componential analysis may refer to the analysis of the time evolution of a given system in terms of its behavior at successive instants of time:

I: A ball is dropped from a height h. What is its speed when it hits the ground?

S: Zero, because when it hits the ground it stops.

In this case, the difficulty arises when the student does not clearly separate the process into instants just before and just after hitting the ground.

Componential analysis may consist of analyzing successively different aspects of the physical situation in question (e.g., writing an equation which refers to the first mass, and then to the second mass, and so on). Here is an example of this specific discomfort.



Transcript 15

Someone exerts a vertical force F on the axle of the massless pulley shown in the figure. A mass m_1 and a second mass m_2 are attached to opposite ends of the rope over the pulley. m_2 is in contact with the floor, while m_1 is not. What is the largest value of F for which m_2 will remain at rest on the floor?

Student has written

$$(m_1 + m_2 + m_p)a = F - (m_1 + m_2) g$$

I: You're looking at everything at the same time.

S: It makes sense to look at the pulley, because that's what F is acting on, but since T_1 and T_2 [the tensions in the ropes on either side of the pulley] depend on the masses, you have to look at them too.

I: Look at the pulley. What touches it? T_1 and T_2. Now, can you find other equations that involve T_1 and T_2? Yes, because the ends of the rope go to m_1 and m_2. The trouble is that you're not breaking it up into pieces.

S: But why can't you do it as a whole?

The last line in Transcript 15 is significant. It illustrates significant resistance to the notion of successive decomposition, this time in the form of looking at different parts of the system.

In all three types of decomposition, the unifying theme is looking at smaller and smaller things which can be readily analyzed, and then joining the partial analyses into a complete solution. Previously, Transcript 4 illustrated a student uneasy in a global sense with the general notion of decomposition.

Still another difference between the mental culture of physicists and students is the former's confidence in solutions derived deductively from first principles, and the student's lack of such confidence. The transcripts which follow below illustrate.

Transcript 16 (Data courtesy Ron Lawson)

[The situation involves accelerating a heavy and a light ice puck across a frictionless table using an air hose. The air blast is applied in a single direction between two green lines on the table, and nowhere else.]

I: What do you know about the term "work"?

S: The definition is that it is the amount of force times the distance.

I: How do you apply that to this situation?

S: You do a certain amount of work on it for the distance between the lines; you apply the force for that distance, and after that point, it goes at a constant velocity with no forces on it.

I: So do we do the same or different amount of work on the two pucks?

S: The same.

I: Does that help us decide if the kinetic energies are the same or different?

S: Well, work equals the change in kinetic energy, so you are going from zero kinetic energy to a certain amount afterwards,... so work is done on each one, but the velocities and the masses are different so the kinetic energies are not necessarily the same.

Transcript 17 (Data courtesy Ron Lawson)

[The situation involves accelerating a heavy and a light ice puck across a frictionless table using an air hose. The air blast is applied in a single direction between two green lines on the table, and nowhere else. This student has been asked to compare the kinetic energies and the momenta of the pucks.]

I: What does kinetic energy mean?

S: I think of 1/2 mass times velocity squared.

I: So what does that imply about which one had the greatest kinetic energy?

S: Actually, if I reasoned that the momenta are the same, then I would have to say that the kinetic energies are the same, because the quantities involved are the same ones... They both [kinetic energy and momentum] incorporate mass and velocity.

In each of these cases, the student employs heuristic reasoning which does work in many instances, but which does not have the reliability of deduction from general principles. Indeed, both students seem to be aware of the principles relevant to the given situation, but "override" the deductive conclusions in favor of their heuristic conclusions.

Neither student seems to give a very high priority to the general principles involved, in these cases, the definitions of the terms involved (Transcripts 16 and 17) and the work-energy theorem (Transcript 16). However, the general principles from which conclusions must be derived (e.g., Newton's laws, Maxwell's equations, definitions of terms) cannot be in conflict; thus, one cannot take precedence over another. Rather, general principles are said to be always applicable, and indeed their application to a given situation must be mutually self-consistent.

I speculate here that these transcripts may reflect an additional difference between mental cultures. Not only does the physicist have a desire for first-principle solutions, he also views them as rigid and mutually consistent. He values deductive first-principle solutions because he believes that a necessary condition for confidence in a solution is being able to cast it in deductive form; indeed, a deductive solution is the only way in which he has a chance of defending his solution against criticism.

By contrast, the principles by which most people live their everyday lives are flexible. For example, this is the essence of the moral dilemma, in which moral principles conflict with one another. No one reasoning strategy works in all situations; a person who attempts to live his life according to one reasoning pattern is viewed as pathological. In addition, most people do not live their lives under constant criticism, in that they do not need to justify their actions constantly. The choice points in life are many, the times when justification is necessary are few; indeed, justification is needed mostly in the resolution of disputes - which are experiences which most people find unpleasant and try to avoid.

There are alternative explanations for the physicist's preference for principle-based deductive solutions. For example, much of the work on expert systems (cf., Larkin et al (1980)) can make a compelling case that what appears to be "reasoning from general principles" is actually pattern-recognition; the physicist has learned to recognize an individual problem as one of a type of problem for which he knows how to apply the relevant principles; in solving a problem, he essentially runs through an algorithm (executes a program) which he knows will give the proper results, even if he cannot predict what they will be beforehand. Good evidence for this explanation is provided by the reactions of expert physicists to problems, the form of which is unfamiliar to them; in many cases, they too stumble, make false starts and errors, and often behave with considerable uncertainty.

One may argue over the proper ordering of teaching directed towards justification (which is the intent of principle-based solutions) and teaching directed towards discovery (which would be the focus of courses which did emphasize designing experiments, formulating problems, guessing relationships, and developing theories). What should be clear is that, at some point, justification is necessary, even if in practice it turns out to be independent of the discovery process. Therefore, at some point in the process, students must learn to justify their arguments, and thus the issues raised in the last two sections will become important.

The last difference between student and physicist mental cultures that I wish to address is the physicist's notion of successive approximation as a powerful way of solving problems. The idea behind successive approximation is that it is possible to construct a useful and meaningful solution to a simplified version of the original problem. One obtains a solution in the right ball-park with relatively little effort, and increasingly more exact solutions with increasing effort; the effort expended is determined by notions of whether the resulting solution is (or will be) "good enough" for the purposes at hand. At the introductory level, this idea leads to the use of idealized problems in which important features are retained for analysis and complicating details ignored.

By contrast, students seem to have a notion that science means exact, and most physics teachers have seen students submit problem solutions or lab reports with 8-digit "precision". In addition, many students seem to have great difficulty with the notion of estimation as being useful. These students seem to look at problem solutions or analyses as either correct or incorrect, accurate or inaccurate. Here are some indicators which emerged from students in a "physics for non-science majors" course on the arms race:

> Asked specifically to estimate the product of 342 and 796, 20% of the class carried out a long-hand multiplication, giving the answer to six significant digits.
>
> Required to make calculations concerning the results of a surprise nuclear attack on the the US by the Soviet Union,

> about 40% of the class (preliminary estimate) expressed the view that the results of the calculations were meaningless because they were so imprecise and also so dependent on the assumptions one made in postulating the attack.
>
> Faced with a lecture based on a model of the arms race in which only the US and the USSR were significant (because together they have the overwhelming majority of existing nuclear weapons), 40% of the class (preliminary estimate) indicated that such a model was oversimplified, and therefore had nothing to do with the current world situation.

I mention these indicators on the assumption that students in "physics for non-science majors" courses will suffer from some of the same difficulties that the poorer students of introductory physics encounter. In the context of introductory physics courses, here are two transcripts which illustrate an unease with approximate models:

Transcript 18

For the acceleration of a block down a friction-filled ramp, student has written correctly

$$a = g \sin \underline{q} - u g \cos \underline{q}$$

I: Now check it. What happens when $\underline{q}$ is 90 degrees?

S: When it's 90 degrees, $\sin \underline{q} = 1$, and $\cos \underline{q} = 0$, so $a = g$.

I: Does that make sense?

S: I'm not sure. Shouldn't friction still affect it?

I: Why should it?

S: Because even though friction gets less, even when $\underline{q} = 90$ degrees, it's still touching the ramp.

Transcript 19

S: You know that problem with the stick that falls straight down on a frictionless surface? Well, they always say that the center of the stick falls straight down, and I never really believe it. It just seems like that could never really happen.

I: Would you feel better if they said that it falls almost straight down, and the less friction there is, the straighter it falls?

S: Yeah, but it could never *really* fall absolutely straight.

2.3 - Discussion

In the transcripts above, I have described a variety of student difficulties which arise from conflicts between students and physics courses. None of these should be very surprising to physics teachers, and indeed, most could report quite similar or related manifestations of difficulty. However, the perspective I have taken in reporting these difficulties rests on the premise that while they are rather unrelated to the intuitive beliefs of students about what will happen in the physical world (which is characteristic of much research on misconceptions in students), they are important to intuitive *epistemologies* of students: when analysis is necessary (Transcript 2), how one decides what analytical methods are likely to be useful (Transcript 4), what constitutes a good reason for doing something (Transcripts 6 and 13), and so on.

I take this perspective because these epistemologies have the potential for guiding at a quite global level the analytical methods that an individual will use in solving a given problem; whether a person thinks (consciously or unconsciously) that a given method will yield useful results is a strong determinant of his actual use of that method, regardless of his mastery of it. [This suggests a possible reason for why students may feel that the physics they see in courses is a game: perhaps they see no a priori reason for using the physicist's analytical tools, other than the teacher's insistence.]

An individual's epistemological beliefs, attitudes, and committments are often tacit, and thus hard to probe. In some cases, direct probes will lead to denial or concealment of the attitude in question; in other cases, the individual may be unable to articulate his views on the subject. In addition, epistemologies and world-views are transmitted in social settings, and a characteristic feature of learning in social settings is that it is informal and often hidden. Thus, the researcher must piece together an epistemology from a variety of indirect clues, and clues may emerge more often over drinks at the bar or in a bull session than in official or formal statements.

With this caveat, let me speculate on some of the reasons that these conflicts do arise. One major feature of the introductory physics classroom is the disparity between teacher and student. The teacher (or textbook author) has years of experience in the field; he has published papers in professional journals or completed a doctoral thesis, and he has experienced *peer review*.

The existence of peer review is central to the socialization of the physicist. Indeed, it is his peer community that judges the quality of his work.[8] Thus, he must internalize its standards if he is to survive. However, peer review does not base its judgements on the private activities of the researchers; rather, it is more concerned with the public research report (published paper). The paper presents conclusions in such a way that they can be criticized, verfied or reproduced independently. Consequently, the actual process by which the researcher reached his conclusions is irrelevant; all that matters is the reconstruction of his path, rationalized in a way that makes it as clear as possible how his conclusions must follow from what is already accepted as correct.[9] Moreover, most physicists would argue that the process of criticism and fault finding is central to progress; only conclusions which have withstood criticism successfully should be allowed to form the basis of future work.[10]

Important elements of rationalized public exposition include deduction from first principles (page 27), lack of ambiguity (page 19), clear specification of variables (Transcript 7), and componential analysis (page 25), i.e., many of the aspects of the physicist's mental culture that I have described above. These are aspects of reasoning that have been explicitly articulated for public access, and it is quite possible that the physicist has internalized them (as standards of his peer community) strongly enough that they affect his teaching.

Indeed, he may have internalized them so well that for problems whose form is very familiar[11], there is no longer a meaningful distinction between the act of creating the solution and the act of justifying it. If so, his attempts to help students in creating solutions may well be perceived as critical and adversarial. In addition, when the physicist must evaluate student work, he may be critical in a manner that is similar to his peer review manner; in both instances, he is likely to search for deviations from accepted forms of explanation.

Turn now to the student. He too has a community in which he has spent a great deal of time and learned to survive, although it is much less well-defined. It is the "everyday" community of "the real world" in which "different rules" apply. It is the world of doing laundry, going to the bank, talking with friends, sleeping in the sun, shopping downtown. The standards of behavior in this world are different: privacy is respected; argument and confrontation are avoided; events have multiple causes; the whole may be more complicated than the sum of its parts; criticism is unpleasant; reliable predictions are difficult if not impossible; principles may conflict with each other; ambiguity is often harmless; justification is often unnecessary. A student who is accustomed to this world may find it difficult to function in the world of the physicist.

Finally, the differences between students and physics teachers may be exacerbated significantly by a superficial similarity which conceals the differences. Consider the structure which teachers present to students: physics is the study of the world around you. Nature is the final judge of the scientist's work. The results which you get in your calculations and measurements should have a reasonable relation to reality.

Students accept this structure. However, the calculations and measurements which students make have a reasonable relation to reality only within the framework of the physicist's epistemology. [Indeed, if this were not true, i.e., if the calculations and measurements which students make were reasonable within the framework of everyday life, it would be absurd to use Ph.D. physicists to teach introductory physics and maintain introductory lab experiments in functioning order. As it is, physics departments don't see anything at all unreasonable about this state of affairs.]

Thus, before the calculations can make sense, the student must somehow learn to make use of the physicist's epistemology. However, this is never said. A review of popular introductory physics textbooks reveals that while every one demonstrates the physicist's epistemology in use, not a single one explicitly discusses it. Rather, they assume that the student understands the value of looking at the world as the physicist does.

Thus, the student finds himself in a position in which he must learn new ways of looking at the world if his results are to make sense and in which he is subject to the judgments of his teacher, even as he is being told that the entire enterprise makes sense and that the "objective reality of nature" will be the judge. This amounts to a "denial of reality", which in more extreme forms is the basis for psychological warfare. I find it understandable that the student may be confused about the "rules of the game".

What can be done about this state of affairs? If one accepts the above analysis, it is clear that change will not be easy. The cultural transmission of committments and values takes place over years, with many explicit reminders. One lecture about the value of the physicist's epistemology will not suffice.

Where to start? There are three elements worthy of investigation, in my view: understanding of the committments of the teacher, understanding of the committments of the student, and understanding how to induce change in the student so that his committments become more similar to those of the teacher.

For the first, the sociology and philosophy of science may prove helpful. Sociologists and philosophers have studied professional scientists in research for many years; their techniques of investigation may prove useful in the study of professional scientists in the classroom. In addition, it may be that certain sociological and philosophical insights into the professional scientist in research may carry over directly into the classroom.

The second area has not been considered an area worthy of investigation until recently. Ethnomethodology (cf., Garfinkel (1967)), human science (cf., Barritt (1980)), and phenomenology (cf., Schutz (1957)) have begun to pay attention to the analysis of everyday experience, but these fields are still on the margins of acceptability. Nevertheless, I believe that they hold significant promise for illuminating an area which has gone unexamined simply because it is so commonplace. In addition, understanding students' epistemologies may be easier when placed in contrast to those of teachers.

The last area has been studied, but in areas possibly unfamiliar to most education researchers. In particular, linguistics (especially English as a Second Language) may be useful in understanding how people give meaning to new terms or learn to describe the world in a different language; indeed, it might address concerns that lead to comments that "physics is like a different language." Psychiatrists and social workers deal with people who are unwilling or unable to change despite the availability of more workable alternatives; their insights might be relevant to students who continue using ineffective methods of problem solving even when they have more effective methods at their disposal.

3 - Closing Comments

As I mentioned before, I consider the work described above suggestive rather than conclusive. More work is necessary in each of the three areas on page 36. In addition, I have the sense that my separation of actors into physics students vs. physics teachers may be misleading; a more appropriate separation may be that of the differences between academic vs. nonacademic life. Finally, it may be that the drawing of correspondences between cultural contrasts and student/teacher epistemological contrasts at a much more detailed level will prove fruitful.

If you find yourself persuaded that the cultural metaphor I propose is a reasonable one, then I think you can agree that this approach can provide a useful complement to more standard cognitive research.

However, if you find yourself unpersuaded of my cultural metaphor, I would hope that you might still consider that non-cognitive factors could affect cognitive performance.

Acknowledgements

The ideas in this paper has been in the germination stage for over four years, but they would not have been expressed in complete sentences without George Posner (Cornell University), who said that my ideas might be sufficiently provocative to start arguements. Thomas Kuhn (M.I.T.) suggested to me in 1981 that a study of the culture of science education would be worthwhile. Margaret Cook (Cornell University) pointed out where I didn't make any sense. Ron Lawson (University of Washington) provided useful data which he was going to use for something else. Thanks to all.

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1. cf., Champagne et al (1980), Trowbridge and McDermott (1980, 1981). These studies are typical - essentially every study I have ever seen (including those for which I have been responsible) has made the direct remediation suggestion.

2. A comparison between this anthropological style of cognitive research and more traditional styles of education research is available (Lin, 1983).

3. This work was similar to but much more primitive than the work that Fred Reif is currently doing at Berkeley (cf, Reif and Heller (1982)).

4. paraphrased from Garfinkel (1967, page 41)

5. ibid.

6. Garfinkel (1967, pp. 42-44) displays several amusing transcripts in which subjects were asked to interject into conversations with friends requests for additional specificity. The result was invariably hostility.

7. There may be subsidiary implications to forcing a student to operate in justification mode upon which I can only speculate, due to a lack of empirical data, e.g., it may frighten the student away from physics, cause feelings of alienation, or even degrade cognitive performance.

8. Nature's role is indirect. From a positivist's perspective, nature, or "objective reality", provides points to which all calculations and measurements made by the community will ultimately converge. Thus, "objective reality" guarantees that the peer review community will make reasonable judgements.

9. cf., Ziman (1968, Chapter 2) on "Scientific Method and Scientific Argument". This book examines in a rather thoughtful way the nature of the scientific enterprise, with particular reference to physics.

10. cf., Merton (1973, Part 3). In an earlier work, Merton was the first to characterize "organized skepticism" as a canon of science, necessary for cumulative progress. Whether this holds for science proper is debatable (cf., (Mulkay (1976)); it does seem valid in the physics classroom.

11. Certainly this is true for the vast majority of problems in introductory physics courses; most teachers would be unlikely to assign a problem whose form was unfamiliar.

STUDENTS' MISCONCEPTIONS IN GEOMETRIC PROBLEM SOLVING

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Please participate in an experiment. After reading this paragraph, try the three geometric problems shown in Figures 1-3. The idea is not only to write an answer to each, but also to indicate the method that led to the solution. If you have any difficulty in solving a problem, try to describe the difficulty. Allow a total of about 7½ minutes or about 2½ minutes per problem. Please read ahead only after you finish all the problems (or when the time allotment is up). (Figures 1-3 on page 216.)

These problems (and other problems described in this report), were used by Max Wertheimer, a founder of Gestalt psychology, in his lectures and demonstrations in productive thinking (Wertheimer, 1945, 1959; Luchins & Luchins, 1970). We have reported elsewhere (Luchins & Luchins, 1979), on a study in which these three problems were presented to college students in private and public colleges in New York State. They were group administered to 86 students in calculus sections (Experiments I & II) and individually administered to 200 students (Experiments III & IV). The 80 Ss in Experiment III were evenly divided by sex and by whether they majored in mathematics (including computer science) or another discipline. It turned out that more of the men majored in the sciences, including mathematics, and more of the women majored in the arts, social sciences, and humanities. Therefore, in Experiment IV, efforts were made to keep the proportion of students in each of these areas similar for both males and females.

Table I (see p.217) gives the percentages of solutions to the problems. In every experiment the least solution occurred for Problem T (triangle), with problem S (square) next, and with Problem C (circle) having the most solutions. On the average, Problem T was solved by only 13%, Problem S by 56% and Problem C by 87%.

There also tended to be sex differences but by no means consistent. For example, in Experiment I, the males showed 32% solution of Problem T in contrast to 0% for the females. But in Experiment II, where most of the females majored in mathematics, they had more solutions of Problem T than the males, 19% compared to 6%. In general, the difference in results between the sexes was smaller than the difference in results between the female mathematics majors and non-mathematics majors. For example, in Experiment III, on the average, in the three problems the males had 57% solution and the females 31%, whereas the female math majors had 53% solution and the female non-math majors only 8% solution. In contrast, there were only small differences between the male math majors who averaged 55% solution and the male non-math majors who averaged 58% solution. Clearly, other differences cut across sex differences. Just as clearly, solutions of the problems did not depend heavily on geometrical knowledge or skills possessed more by math majors than others.

Recall that of the total of 286 students in Experiments I through IV, only 13% failed Problem C while 44% failed Problem S. It is of interest that Problems C and S require essentially the same geometric knowledge--the formula for the area of the square--but in Problem C this is rather obvious whereas in Problem S it requires some restructuring to bring the solver to the realization that the required area is equal to the area of the square.

To help bring about restructurization in order to enhance problem solving, a series of hints was available for each problem. Under the individual administration in Experiments III and IV, if S had not spontaneously solved the problem within 2½ minutes, four hints were given, one at a time.

In Experiment III, of the 20 male non-mathematics majors, 16 required hints to solve Problem T; three needed only Hint 1; one needed only Hints 1 and 2; three needed Hints 1, 2 and 3; and nine needed all of Hints 1, 2, 3 and 4. These nine Ss constitute 45% of all 20 male non-mathematics major and 56% of the 16 who needed any hints. For

Problem T, in Experiment III, 56, 51, 21 and 9 % of those who needed hints were given all four hints for the male non-mathematics majors, the female mathematices majors, the female non-mathematics majors, and the male mathematics majors, respectively. Based on all students, the corresponding percentages were 45, 35, 20 and 0. Similar trends held in Experiment IV and in Problem S. In short, the percentages of those who needed all of the hints tended to be highest among the male non-mathematics majors, next highest among the female mathematics majors, lower among the female non-mathematics majors, and lowest among the male mathematics majors. As we noted elsewhere (1979):

> Some clues to reasons for these trends may be found in the Es' impressions of reactions to the hints. The males said overtly, or seemed to assume at the onset, that they would not need hints. In the case of the male mathematics majors, this was generally true. The male Ss usually seemed embarrassed when it turned out that they needed hints for such "easy problems." The more hints the male non-mathematics majors needed, the more flustered they seemed to become. They murmured phrases, such as "How stupid of me" or "What a jerk I am," or used stronger language. The female mathematics majors seemed only slightly less embarassed at requiring hints. As one put it, "I guess I should change my major." Many women, both mathematics majors and others, often explained, on first seeing the problem, that they did not like geometry or that they were not good at it. (Also, more women than men selected geometry as their least favorite mathematics subject.) The female non-mathematics majors generally said or assumed at the onset that they could not do the problems without hints, and seemed less flustered at needing them. They listened carefully as a hint was given, and it seemed to help them to focus on and restructure the problem so as to get closer to a solution. It may also be that they were more accustomed to needing and accepting help with mathematical problems. In short, it may be that the male non-mathematics majors, and to only a slightly lesser extent, the female mathematics majors, were more ego-involved about their success in solving the problems and, therefore, were less open to hints given to restructure the problem situation (1979, p. 264).

In Problem T, the aims of the successive hints were to point out that the square and the parallelogram formed two large triangles, to recall that each triangle has its area given by base times height, to note that each triangle has base a and height b, and that shifting the triangles can result in a rectangle of sides a and b.

Many students resisted shifting the triangles, and could not visualize the resulting rectangle, even after the four hints. Here, as well as in some of the other problems, they showed what might be called a "static" misconception, that is, they assumed that a figure, as given in a problem must stay unchanged. Or they were not aware that the figure could be subjected to transformations which would not affect the area to be found.

A related misconception was that the problem had to be done as specified. Since it asked for the sum of the areas, some students proceeded to find the two areas and add them--but they had difficulty in finding the area of an oblong parallelogram. The majority found the area of the square, which they realized was a^2, but few recognized that the base of the parallelogram had length b-a, and even fewer recognized that the height was a. Those who were successful in calculating the area in this manner obtained $a^2 + (b-a)a = a^2 + ba - a^2 = ba = ab$. This is, of course, the answer obtained by shifting the triangles to form a rectangle, as suggested in the hints.

Many Ss tried to prove at the onset that the two little triangles which protruded from the square in Problem T are congruent. Some students jump to the conclusion of "show congruence" when they see two triangles of about the same size and shape, whether or not it is relevant to the problem at hand.

In Problem S, some students did not consider the semicircles even after Hint 1. Most of them were not readily able to see that the areas of the two semicircles together equaled the area of the circular window, as suggested in Hints 2 and 3. The majority tried to find the area of the square, then subtract the area of the circle, and then add the areas of the semi-circles. That and-summative approach often led to errors. Some complained they did not know the formulas for the area to be covered with gold leaf. Even after Hint 4, Ss had difficulty in restructuring the figure so that they realized that all that was needed was the area of the square, since it equaled the required area.

Experiment V

Problems T, C and S were also administered to over 200 more students, without any hints. They were given, toward the end of the school year, to geometry classes in a private high school for girls (H.S. Geometry). They were also given to students who had recently completed their junior or senior year of high school and were attending summer courses at Rensselaer Polytechnic Institute (RPI). One summer class at RPI consisted of educationally disadvantaged minority group members taking non-credit college preparatory mathematics (Min. A). Another class, taking a regular college credit course, consisted mainly of minority members (Min. B). The results are summarized in Table 2 (see p.217).

In every group the frequency of solutions showed the same trend as in the previous experiments: Problem T had the least solutions, Problem C the most, and Problem S in between. Overall the females showed relatively less solutions than the males. The high school geometry girls showed the least solutions of all the groups in this experiment: only 5% solution of Problem T, 32% solution of Problem S, and an average of 39% solution. The sex differences were small in the RPI group. And in Minority A, the trend went in the opposite direction, with the few females showing a higher frequency of solution in each of Problems T, C and S than the males. These results testify to the caution needed in generalizing about the mathematical performances of the sexes and of minority group members.

The present experiment did not end with Problems T, C and S. Please try the three problems designated as Tasks I, II and III (see Chart 2, p. 217).

There were three more such problems, designated as Tasks IV, V and VI. Table 3 (see p.217)gives the percentages of solutions of these tasks as well as their means with and without Task VI (which was somewhat different in nature). As with the earlier problems, the females tended, on the whole, to show somewhat less solution than the males. But the sex differences were much smaller than the differences between problems.

Of particular interest are Tasks I and III (Chart 2, p. 217 and Table 3A, p. 217)since they both attempted to describe the same object, a tetrahedron (a solid with a triangular base and triangular faces). The description in Task I was what Wertheimer called contra-structural since it did not follow the natural division of the structure of the solid, whereas the description in Task III was what he called pro-structural. The pro-structural description yielded more solutions. For example, the high school geometry girls showed only 22% solution of Task I in contrast to 85% solution for Task II, in increase of 63%, obviously statistically significant. The increases were in the same direction for most of the other groups although more modes in some cases: 26% and 32% more solutions in Task III for the RPI males and females respectively. In Minority A, the males had 36% solution of Task I and 100% solution of Task III. The females, however, in this group had 60% solution of each problem.

What is interesting is that, on the whole, sex differences in Task I favored the males and were statistically significant. In Task III, however, sex differences were virtually wiped out and not statistically significant at acceptable levels.

Similar trends of results, although not so marked, were found for other problems. For example, in Spatial Task II (Problem 5), which gave a pro-structural description, the private high school girls had 93% solution, even more than the RPI males.

Such results led one of the authors to draw the following conclusion:

> "The study hints that it may be more fruitful to find structurally appropriate methods of teaching mathematics than to argue over possible sex differences in mathematics. More generally, methods of teaching mathematics may make for greater variations in learning than do sex differences" (1981, p. 417).

There is an important educational implication here: Misconceptions may stem from the stimulus side, from the manner in which problems and materials are presented. On the other side of the coin, understanding of the structure of objects, and presentations in line with the structure, may encourage correct conceptions and facilitate problem solving. Pro-structural descriptions may improve problem solving for both boys and girls, and minimize sex differences.

Why did Task III bring about recognition of the tetrahedron and Task I work against it? In part, the answer may be that the pro-strctural description led Ss to see a three-dimensional object whereas the contra-structural one led more often to the drawing and describing of two-dimensional objects. Perhaps an Einstellung effect or habituation was also involved since Task I came immediately after the two-dimensional geometric tasks. However, this was not the sole reason since throughout Tasks I-V, the most frequent misconception was that two-dimensional objects were involved. This can be seen from Table 4 which gives the frequencies of errors involved in failures to solve these problems (see p.218).

Now please try Task VI; Imagine before you a sugar cube standing on a vertex, with the top vertex above the lower vertex. The cube is cut horizontally into halves. Draw or describe the shape of the cut surface.

Before turning to the results in Spatial Task VI (Problem 9), we emphasize that this task differed considerably from the other spatial tasks. Whereas these other tasks began with lines and planes and developed a three-dimensional object, this task began with a three-dimensional object and asked for a two-dimensional one.

As you saw (in Table 3), very few Ss solved this problem--only 12 out of 151 males and no females in this study. It should be noted that even some mathematicians have difficulties in visualizing the surface (which is not a square, diamond or rhombus). A recent text (*Invitation to Geometry*, by A.Z Melzak, Wiley, 1983) gives three demonstrations that such a cut is a hexagon. But it is not clear that any of these is pro-structural in nature. What kind of description can be given to help Ss to be aware of the shape of the cut? Will such an approach improve solution and eliminate sex differences?

More generally, what can be done to make educators more alert to methods of presentation which do take structure into account?

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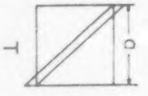

Figure 1

IN THE SQUARE WITH THE PARALLELOGRAM STRIP ACROSS IT, THE LINES OF LENGTH a AND b ARE GIVEN. FIND THE SUM OF THE TWO AREAS, THAT IS, THE SUM OF THE AREAS OF THE SQUARE AND OF THE PARALLELOGRAM.

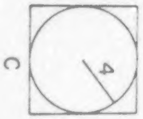

Figure 2

A CIRCLE OF RADIUS 4 IS INSCRIBED IN A SQUARE. FIND THE AREA OF THE SQUARE.

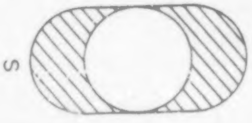

Figure 3

A CIRCULAR WINDOW WAS DECORATED IN THE FOLLOWING MANNER. THE PAINTERS DREW TWO VERTICAL LINES, WHICH WERE TANGENT TO THE CIRCLE AND WERE OF THE SAME LENGTH AS THE DIAMETER OF THE CIRCLE, ONE TO THE LEFT AND ONE TO THE RIGHT OF THE CIRCLE. THEN THEY ERECTED SEMICIRCLES ON THE ENDS OF THESE TANGENTS, ONE SEMICIRCLE ABOVE AND ONE BELOW THE CIRCLE. THE PAINTERS HAD TO COVER WITH GOLD LEAF THE REGION BETWEEN WHAT THEY HAD DRAWN AND THE CIRCULAR WINDOW. IN ORDER TO KNOW HOW MUCH GOLD LEAF WAS NEEDED, THEY HAD TO KNOW THE AREA OF THIS REGION. THEY WERE ABLE TO FIND THIS AREA, KNOWING THAT THE DIAMETER OF THE CIRCULAR WINDOW WAS 10 FEET. HOW WOULD YOU FIND THE AREA?

TABLE 1
PERCENTAGES OF SOLUTIONS OF PROBLEMS T, C AND S
IN EXPERIMENTS I-IV

Experiment/Ss	Problem T	Problem C	Problem S	Mean
Experiment I				
36 Ss	28	97	78	68
31 M	32	97	81	70
5 F	0	100	60	53
Experiment II				
50 Ss	10	96	60	55
34 M	6	94	59	53
16 F	19	100	63	60
Experiment III				
80 Ss	15	75	41	44
40 M	17	95	58	57
40 F	13	50	25	31
20 M Math	15	95	55	55
20 Nonmath	20	95	60	58
20 F Math	20	90	59	53
20 F Nonmath	5	20	0	8
40 Math	17	93	53	54
40 Nonmath	13	58	30	33
Experiment IV				
120 Ss	8	88	59	52
62 M	11	92	69	58
58 F	5	84	48	46
26 M Math	12	92	69	58
36 M Nonmath	11	92	69	57
30 F Math	7	93	63	54
28 F Nonmath	4	75	32	37
56 Math	9	93	66	56
64 Nonmath	8	84	53	48

Table 2
PERCENTAGES OF SOLUTIONS OF PROBLEMS 1, 2 AND 3

Group		Ss	1 Problem T	2 Problem C	3 Problem S	Mean
H.S. Geom.		41	5	80	32	39
RPI	M	79	29	94	85	69
	F	22	14	95	82	64
	TOTAL	101	26	94	84	68
Minority A	M	25	16	72	56	48
	F	5	20	100	60	60
	Total	30	17	77	57	50
Minority B	M	27	37	100	74	70
	F	14	14	86	71	57
	TOTAL	41	29	95	73	66

CHART 1

T Problem

Hints: (A) Point out two large triangles.
(B) Note that area of triangle - 1/2(base)(height).
(C) Note that A is base and B is height of each triangle.
(D) Suggest shift of two triangles to form rectangle.

C Problem

Hints: (A) Radius of inscribed cricle is 4.
(B) Draw horizontal radius.
(C) Extent radius to diameter.
(D) Move diameter vertically to side of square.

S Problem

Hints: (A) Draw horizontal tangents to the circle.
(B) Areas of semicircles together equal area of the circle.
(C) Place semicircles into the square and onto the circle.
(D) Area of square equals desired area.

CHART 2

I. **Imagine before you in space a horizontal line, about one foot long. Parallel to it and a foot above it is another line of equal length. Turn the top line 90 degrees, about its center point, in the horizontal plane. Now connect both endpoints of the top line with both endpoints of the bottom line. Connect all endpoints to each other. What figure do you see? Describe it and draw it.**

II. **Imagine before you in space a regular pentagon, which is a five-sided equilateral polygon. The pentagon is lying in the horizontal plane. Place a point about one foot above its center point. Connect this point, which is above the pentagon, with all the vertices or corners of the pentagon. What figure do you see? Describe it and draw it. Is the figure the same as or different from I?**

III. **Imagine before you in space an equilateral triangle in the horizontal plane. Put a point above its center and connect this point to the vertices of the triangle. What is the resulting figure? Describe it draw it. Do you see the figure that was described in the first task? What is your trouble? Record all your difficulties.**

TABLE 3. PERCENTAGES OF SOLUTIONS OF TASKS I-VI

GROUPS/Ss		TASKS I	II	III	IV	V	VI	MEANS I-VI	I-V
H.S. GEOM.	F 41	22	93	85	0	66	0	44	53
RPI	M 79	68	86	94	13	90	13	61	70
	F 22	59	82	91	14	82	0	55	66
	TOTAL 101	66	85	93	13	88	10	59	69
MIN. A	M 25	36	96	100	12	88	0	55	66
	F 5	60	80	60	40	60	0	50	60
	TOTAL 30	40	93	93	17	83	0	54	65
MIN. B	M 27	67	85	96	52	81	7	65	76
	F 14	61	79	86	57	79	0	60	72
	TOTAL 41	65	83	93	54	80	5	63	75

Table 3A

COMPARISON OF PERCENTAGES OF SOLUTIONS AND OF SEX DIFFERENCES FOR H.S. AND RPI GROUPS IN TASKS I AND III

GROUP	Ss	TASK	%	GROUP	Ss	TASK	%	DIFF	T-VALUE	P-VALUE
H.S. GEOM.	41	I	22	H.S. GEOM.	41	III	85	63	7.38	APPROACHES 0
H.S. GEOM.	41	I	66	RPI TOTAL	101	I	22	44	5.50	APPROACHES 0
H.S. GEOM.	41	III	93	RPI TOTAL	101	III	85	8	1.31	.19
RPI FEMALES	22	I	59	RPI FEMALES	22	III	91	32	2.64	.01
ALL FEMALES	63	I	35	ALL FEMALES	63	III	87	52	7.07	APPROACHES 0
RPI MALES	79	I	68	RPI MALES	79	III	94	26	4.41	.002
ALL FEMALES	63	I	35	RPI MALES	79	I	68	33	4.14	.004
ALL FEMALES	63	III	87	RPI MALES	79	III	94	7	1.40	.16

TABLE 4. PERCENTAGES OF FAILURES TO SOLVE TASKS I-V WHICH INVOLVED VARIOUS ERRORS.

GROUP	H.S.	R.P.I.			M IN A		
	GEOM.	M	F	TOTAL	M	F	TOTAL
(Ss)	(41)	(79)	(22)	(101)	(25)	(5)	(30)
# FAILURES	96	120	38	158	49	10	59
ERRORS							
F. TWO-DIMENSIONAL OBJECT	31.2	27.5	36.8	29.7	26.5	10	23.7
D. DID NOT CONNECT VERTICES	16.6	23.3	23.7	23.4	16.3	30	18.6
C. ROTATED INCORRECTLY	12.5	5.0	2.6	4.4	16.3	0	13.5
B. DID NOT ROTATE	9.3	2.5	2.6	2.5	22.4	10	20.3
E. USED CURVED LINES	10.4	0.8	2.6	1.2	2.0	30	6.7
G. WRONG BASE OR NO BASE	7.3	12.5	10.5	12.0	9.6	20	11.4
H. OMITTED DIAGONAL	4.2	11.7	5.3	10.2	0	0	0
J. METHOD UNCLEAR	3.1	15.8	10.5	14.5	2.0	0	1.7
I. OMITTED PROBLEM	5.2	0.8	5.3	1.3	10.2	0	8.5

AN EXAMINATION OF STUDENT MISCONCEPTIONS IN GENETICS

by

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INTRODUCTION

In recent years great emphasis has been placed on ways in which student knowledge and misconceptions in science can be revealed. This emphasis has arisen out of Ausubel's (1968) notion that any teaching should be based on teacher knowledge of the relevant concepts that already exist in the learner's cognitive structure when entering the instructional setting. To help elicit such information about a student the technique of concept mapping (Novak 1976,1979,and 1980) has been used by reseachers with students over a large age range and in a number of discipline areas.

Although concept mapping has proved to be a valuable research strategy, there seems to be little evidence that teachers are using the technique to any great extent. If concept mapping is the powerful technique that many claim it to be, how can teachers be introduced to it?

In Victoria, Australia, the majority of students in the final year of secondary schooling (year 12) sit an 'external' examination, the results of which are used, among other things, for entry into tertiary institutions. The examination papers go into hundreds of schools and are seen by teachers in those schools. So here was a vehicle for introducing teachers to the idea of concept mapping even if the term itself wasn't used. This paper reports on the results of the inclusion of a 'concept map' question on the 1982 Biology examination paper prepared for the Victorian Institute of Secondary Education. Biology is the most popular choice subject taken by students and in 1982, 9207 students presented for the Biology examination (cf compulsory English approximately 25,000).

The proposed setting for the concept map question was quite different from any previously reported and a number of questions had to be considered:

1. How does one get 9207 students to draw a concept map without calling it that, knowing that the students most probably will not have done one before and will not be able to ask any questions?

2. Would the team of markers be able to make appropriate judgements to give students marks that would reflect their understanding of concepts?

3. To what extent would concept mapping serve as a valid discriminator in an external exam?

Obviously points 2 and 3 could only satisfactorily be considered after an appropriate solution could be found for 1 and the question included on the examination paper.

THE QUESTION

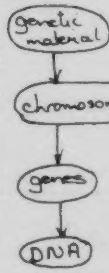
One area of biology in which students have learning difficulties is genetics (Longden 1982, Radford and Bird-Stewart 1982), a topic that makes up about 15% of the year 12 Biology course in Victoria. The course is prescribed by the Victorian Institute of Secondary

Education (1980) and Appendix 1 lists the examinable ideas in genetics. The decision was made to write a question involving, in particular, the first of those ideas, especially as past examination papers had revealed a lack of understanding in that area (Reports of Examiners 1972 -).

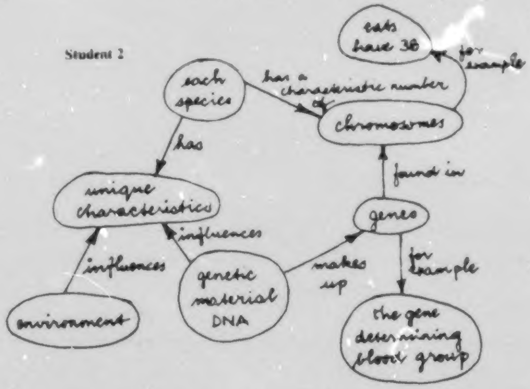
A range of question types is included in the Biology paper - true/false items, multiple choice items, short extended response items and longer essay-type questions. A student is expected to attempt all questions. The 'concept map' question finally included on the paper was a six mark, short extended response item and is given below.

Two students were asked to represent their understanding of the genetic material in a diagrammatic form. Their diagrams were as follows:

Student 1



Student 2



a. Student 2 was given more marks than Student 1. Explain how the diagram produced by Student 2 shows that he has a greater understanding of the topic? 2 marks

b. Make a diagrammatic representation of your understanding of genotype and phenotype and the relationship between them. Give specific examples where appropriate. 4 marks

Total 6 marks

RESULTS AND DISCUSSION

Part (a) of the question was aimed at providing a model for students that could guide them for part (b) of the question. Could students make generalisations about part (a) that they could then elaborate within the context provided in part (b)?

For the purpose of the analysis reported in this paper, 30 answers were selected from the total scripts. The scripts were chosen on a glance impression that the full range of student ability would be included. No attempt was made to bias the- selection toward those scripts that included many or particular misconceptions. As it turned out, the chosen group performed better than average in terms of marks obtained for the question (all students $\bar{X} = 2.5$, $S = 1.2$: Sample $\bar{X} = 3.0$, $S = 1.7$).

In answer to part (a) student comments could have been related to four main areas (this is in fact how the question was marked with students being given 1/2 mark for each idea given). These areas and the number of students in the sample making reference to them are as follows:

	More ideas included	Relationships between ideas explained	Web of ideas	Examples given
Number of students (max 30)	14	11	5	20

It appears from these results that the majority of students acknowlegded the importance of examples and in fact a further prompt with regard to this was given in part (b) of the question. It would seem reasonable then to expect students to follow that model in preparing their own concept maps. This in fact was not the case as the following analysis of student answers to (b) shows.

	Examples given in answer to (b)	No mention of examples in answer to (b)	Total
Presence of examples given in (a)	10	10	20
No mention of examples in (a)	5	5	10
Total	15	15	30

So a transferability seems not to be operating. A student who was aware of the importance of examples in part (a) was no more likely to include them in part (b) than was a student who had overlooked them in (a) in spite of the additional prompt.

In addition, the lack of identification of cross linkages to form a web in (a) did not inhibit their production in response to part (b). Twenty two of the 30 students included elements of webbing in their maps compared with five who considered it in part (a).

On the whole, students were unable to generalise about the positive attributes of the answer of Student 2 in part (a) of the question. Examiners have often criticised students (Reports of Examiners 1972 -) for their lack of specificity in answering particular questions. It also seems that students have difficulty in drawing generalisations when appropriate. Students tended to repeat the words included in the sample maps. For example

"Student 1 has given DNA, genes, chromosomes and genetic material. Student 2 has indicated that chromosomes consist of genes which are made up of DNA (genetic material) and that DNA influences the characteristics of a species. He has also indicated the environment. Student 2 has given examples to illustrate his understanding."

Four of the 30 students expressed some concern regarding the arrows in the given maps; for example "Student 1 is pointing arrows in the wrong direction.". Arrows are used in a number of distinct ways in scientific diagrams including as labels, for measurement, as forces, to represent changes, and to illustrate relationships and students are often confused in their understanding of diagrams because of the presence of these arrows (Schollum 1983). In addition to the students who explicitly mentioned arrows in part (a), others gave placements in their own maps inconsistent with the linking words while others drew arrowheads at both ends of the connecting lines which appeared to make expression of the relationship between parts more difficult (see Figure 1). The misconception that arrows can 'only go one way' has implications for the teaching of biology. It is as valid to commence a study of the whole organism moving down through levels to the cell as it is to commence with a cell and to move up to the whole organism. Students should be given opportunities to consider topics from a number of different points of view. It is the linking relationships and the way in which they are expressed that will give an indication of the understanding or otherwise of the concepts involved.

Some workers have indicated, either explicitly or implicitly, a degree of hierarchy in concept maps and Novak (1981) presents a comprehensive form for assessing student-constructed concept maps that is based on a hierarchical marking system. No hierarchy requirement was built into the marking scheme applied to the 9207 student concept maps. Marks were awarded as follows:

For use of each of the following terms with an indication that the meaning of the term was understood

genotype	1/2 mark
environment	1/2 mark
phenotype	1/2 mark
The 3 concepts used in a correct relationship	1/2 mark

The remaining two marks were obtained by demonstrating an understanding of up to 3 other relevant concepts (1/2 mark each) and giving up to 3 additional correct examples (1/2 mark each).

This marking scheme was agreed by the panel of markers involved after lengthy discussion and a detailed examination of a number of student scripts involving practice marking to ensure that consistency could be obtained. Following this agreement routine marking was carried out in which all extended response questions are marked independently by two different markers. A third marker is involved if the first two marks differ by more than 2. For an answer given marks differing by 2 or less, a student receives the average mark.

Some answers to part (b) of the concept map question, taken from the sample of 30 are given in Figures 1 to 6. An analysis of the 30 sample answers revealed a number of misconceptions including:

1. The Punnett square is a relevant inclusion in the answer to any genetics question. The two students who gave (incorrectly) details of a genetic cross within a Punnett square were unable to tie it in any way to the context of the question. The misconceptions of students accumulated as a result of inappropriate use of Punnett squares and the ratios they elecit is dealt with elsewhere by Kinnear and others at this conference.

2. The concepts genotype and phenotype refer to characteristics that are influenced by a single gene only. For example see Figure 2.. Where students did include an example of a multifactorial characteristic , for example height and pigmentation in Figure 1, they appeared to be unable to translate that in terms of the genotype. Although 16 students elaborated their understanding of genotype, only 7 went beyond the notion of single gene involvement with a particular characteristic. Nineteen students elaborated on phenotype however only 6 went beyond the concept of a single characteristic.

3. A lack of appreciation for the complex nature of the environment and an inability to be specific about its effect. Students had obviously read the traditional statement

   genotype + environment = phenotype

   and one student gave that without further elaboration. Others made attempts, with more (see Figure 4) or less success, to build that expression directly into their concept maps. Although 25 of the 30 students included the notion of environment in their answers only 10 were able to give specific examples (compare Figures 1 and 2).The examples given tended to emphasize external factors such as dyed hair in Figure 5 however others such as Figure 1 implied an internal effect because of diet. The 10 examples for environment included 4 general comments about the effect of the environment on identical twins (see Figure 3). Perhaps the most interesting specific point gleaned about student understanding of environment was their apparent lack of inclusion of mutagenic agents in that role. An analysis of this idea reveals the following.

	Number of Students
Mutagenic agent included as part of the environment	2
Mutagenic agent separate from environment	5
Reference to environment without inclusion of any notion of mutagenic agent	18
Reference to mutagen or its agent without inclusion of any notion of environment	0
No specific reference to either environment or mutagenic agent	5

The student map in Figure 6, while limited in some aspects, does show a comprehensive understanding of the role that the environment can play in its impact on both genotype and phenotype. Contrast this with the map in Figure 5 in which the student specifically excludes the environment from having an impact on the genotype, however does acknowledge that mutations and the consequent changes in genotypes do occur. This lack of connection between mutations and the possibility of involvement of environmental factors may be supported by the tendency to teach about mutations as spontaneous events. In addition, much of the text material available on the topic of mutations is misleading (Mahadeva and Randerson 1982).

So the markers were able to perform their task and it was possible to analyse student misconceptions in this way but how did teachers and students react to the 'new' type of question? Because of the guarantee of confidentiality of results it was not possible to discuss a particular map with its author. However it was possible to carry out a survey among 35 students engaged in tertiary study in 1983 who had successfully completed Higher School Certificate including Biology in 1982. Of these students none had previously drawn a concept map. Their reaction to the question can best be summarised by the following two quotes:

Student A
"I found this question quite easy although the diagram I drew seemed fairly simple to be worth 4 marks even after giving specific examples and I wasn't sure if what I had written was exactly what they required."

Student B
"I found part (a) of the question to be quite straightforward but part (b) was different to anything we'd ever done before so I had to do a lot of thinking before I attempted this quesion on paper. I didn't really like part (b)."

The reaction of students seemed to be dependent on how well they thought they had scored on the question.

Anecdotal evidence from teachers seems to indicate that they were not too concerned about the 'new' type of question. Comments made included:

"I was delighted when I saw that question. I always get my kids to summarise their work in that way."

"It was an unusual question but really .... I suppose .... you could ask questions in that way on any topic."

"I didn't like it when I first looked at it."

"That question was a bit different."

There have been a number of teachers who have asked the different members of the Panel of Examiners whether such a question will be asked again. Obviously teachers see virtue in using such a technique if it is to be considered an examination technique. Whether they will see its virtue as an instrument in classroom teaching remains to be seen.

In the final analysis, the success of this question in an external examination must be judged in terms of how well it discriminated between the candidates. The correlation coefficient of this question to the performance of students on the whole examination and to other questions will be the critical information in making that judgement. Unfortunately that information was not available at the time of writing this paper and must be reported at another time.

FIGURE 1

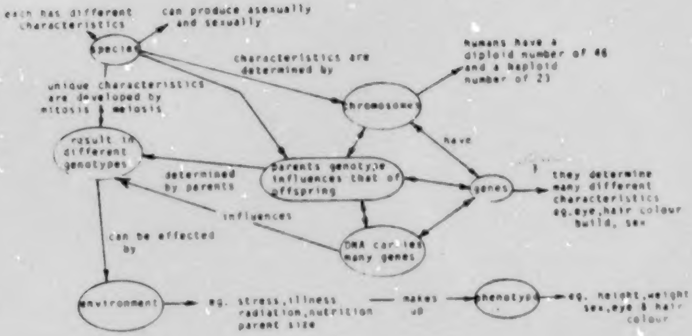

each has different characteristics
can produce asexually and sexually
species
characteristics are determined by
Humans have a diploid number of 46 and a haploid number of 23
unique characteristics are developed by mitosis & meiosis
chromosomes
result in different genotypes
have
parents genotype influences that of offspring
determined by parents
genes
they determine many different characteristics eg.eye,hair colour build, sex
influences
can be effected by
DNA carries many genes
environment
eg. stress,illness radiation,nutrition parent size
makes up
phenotype
eg. height,weight sex,eye & hair colour

FIGURE 2

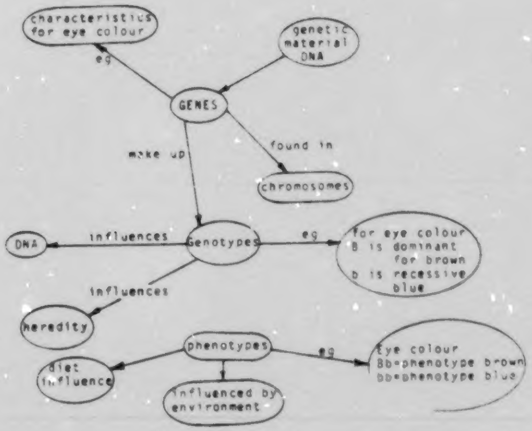

characteristics for eye colour
genetic material DNA
eg
GENES
make up
found in
chromosomes
DNA
influences
Genotypes
eg
for eye colour B is dominant for brown b is recessive blue
influences
heredity
phenotypes
eg
Eye colour Bb=phenotype brown bb=phenotype blue
diet influence
influenced by environment

FIGURE 3

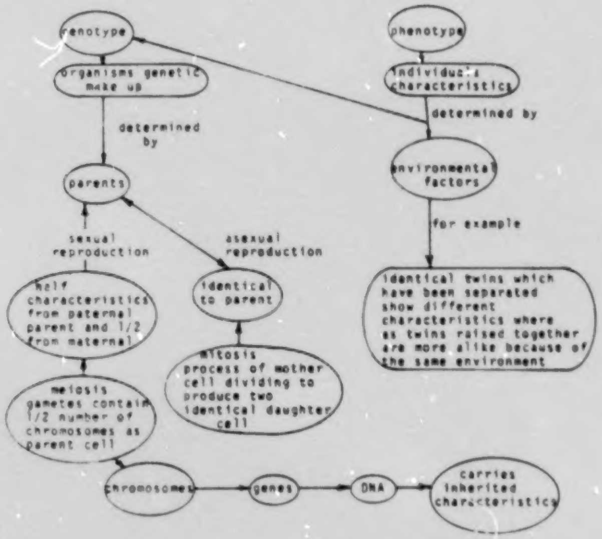

genotype
phenotype
organisms genetic make up
individual's characteristics
determined by
determined by
parents
environmental factors
sexual reproduction
asexual reproduction
for example
half characteristics from paternal parent and 1/2 from maternal
identical to parent
identical twins which have been separated show different characteristics where as twins raised together are more alike because of the same environment
mitosis process of mother cell dividing to produce two identical daughter cell
meiosis gametes contain 1/2 number of chromosomes as parent cell
chromosomes
genes
DNA
carries inherited characteristics

FIGURE 4

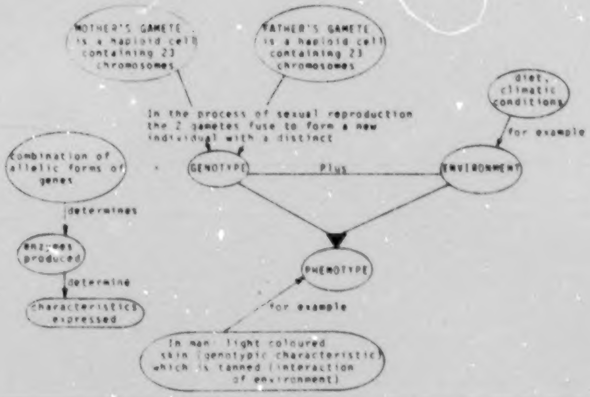

MOTHER'S GAMETE is a haploid cell containing 23 chromosomes
FATHER'S GAMETE is a haploid cell containing 23 chromosomes
diet, climatic conditions
In the process of sexual reproduction the 2 gametes fuse to form a new individual with a distinct
for example
Combination of allelic forms of genes
GENOTYPE
Plus
ENVIRONMENT
determines
enzymes produced
determine
characteristics expressed
PHENOTYPE
for example
In man: light coloured skin (genotypic characteristic) which is tanned (interaction of environment)

FIGURE 5

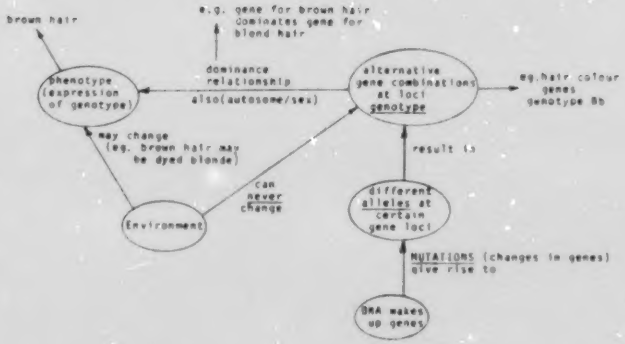
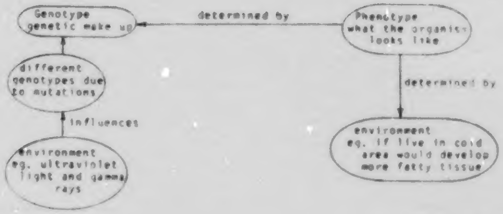

brown hair
e.g. gene for brown hair dominates gene for blond hair
dominance relationship
also(autosome/sex)
phenotype (expression of genotype)
alternative gene combinations at loci genotype
eg.hair colour genes genotype Bb
may change (eg. brown hair may be dyed blonde)
can never change
result in
Environment
different alleles at certain gene loci
MUTATIONS (changes in genes) give rise to
DNA makes up genes

FIGURE 6


Genotype genetic make up
determined by
Phenotype what the organism looks like
different genotypes due to mutations
determined by
influences
environment eg. ultraviolet light and gamma rays
environment eg. if live in cold area would develop more fatty tissue

APPENDIX 1

IDEAS IN GENETICS - FOR THE HIGHER SCHOOL CERTIFICATE CORE EXAMINATION IN BIOLOGY 1982 (Victorian Institute of Secondary Education - 1980)

a. The characteristics of any organism can be interpreted as due partly to an inheritance from previous generations and partly to the influence of environmental factors during that organism's lifetime.

b. In most organisms continuity of life involves the transmission of chromosomes from cell to cell in growth and in cell replacement, and from generation to generation in reproductive processes. In most higher plants and animals which reproduce sexually, two homologous sets of chromosomes occur in the nuclei of somatic cells.

c. Meiosis results in cells with a single chromosome set, consisting of one chromosome of each pair. The chromosome number is restored at fertilisation, when the chromosome sets contributed by the gametes combine.

d. Offspring produced sexually show greater variability than those produced asexually.

e. Chromosomes affect the characteristics of organisms: portions of chromosomes determine identifiable attributes of the organism, including, in bisexual species, maleness and femaleness.

f. Alternative inherited characteristics are determined by different forms (alleles) of the chromosomal unit (gene) influencing that characteristic. New alleles arise rarely by mutation. The effect of a particular allele may be masked by that of the alternative allele carried on a homologous chromosome (dominance).

g. The frequencies of the various genotypic classes amongst the offspring of a particular cross are determined by the frequencies of each class of gamete.

h. When alleles of two or more genes located on different chromosomes are followed in a cross, the patterns of inheritance of the characteristics involvedresult from an independent distribution to the gametes of the maternally and paternally derived chromosomes of each homologous pair.

j. The chromosomes consist largely of a complex compound, deoxyribose nucleic acid (DNA) which provides the chemical basis underlying hereditary transmission of characteristics from one generation to the next.

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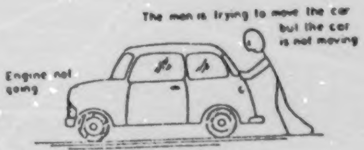
*Influence of Cognitive Instruction on Misconceptions in Physics and Mathematics

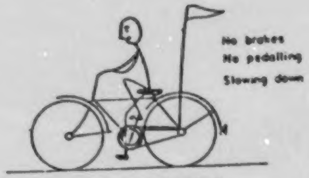
H.C. Mehl
J.D. Volmink

Physics and Mathematics Education is seeing at present, a burgeoning research effort in the field of misconceptions or alternative conceptions. It is clear that, students bring with them to a study of science and mathematics, a vast complex of ideas and concepts from their own experience in life. This residual knowledge interacts with what they are taught and the results are not always what instructors assume they are. The scientific ideas which students bring to the classroom have been[1] considered either by clinical interviews of varying duration or by paper-and-pencil tests by many researchers.

In trying to determine children's ideas about force, Osborne and Gilbert (1) cite the following as examples of what children believe in answers to the "Interview-about-instances cards" given to them, two examples of which follows below.



Is there a force on the car ?



Is there a force on the bike ?

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*Presented at the International Seminar on Misconceptions in Science and Mathematics, Cornell University, June 19-22, 1983.

Car: "No because it can't feel anything, but there is a force on the man because he has to push it and that puts a force on him." (9 year old)

Bike: "No... not really because he is not pedalling or anything." (9, 11, 13 year old)

Bike: "Yes, it is putting force on by itself." (9 year old)

Bike: "Yes because it is forcing itself to stop." (9 year old)

Even after considerable instruction in science (British O and A levels), students give the following responses to the "bike" question.

> "There's a force because of the bike's own mass... the mass of the bike has come to such a speed that it won't just stop straight away... the force is still there... in the bike... the force was transferred to the person pedalling... and it is now still adherent in the bike... the bike still moves forward."
>
> (19 year old)

It is perhaps relevant at the outset to ask what exactly is being probed in determining students misconceptions. It is, of course, hoped that a clear view is being obtained of their understanding of a particular concept, law etc., i.e., of the content of the subject. However, the product of teaching (i.e., the concepts teachers hope students will learn) is inextricably bound up with the process of learning it. Cognitive functions are brought to bear on the learning process which will inevitabily influence not only what is learnt, but also how it is learnt. Thus it becomes a daunting task to unravel the two in any testing procedure.

In this paper an attempt will be made to place this process-product dichotomy in perspective from 2 viewpoints:

(a) deficient cognitive structures which students may have as elaborated by Feuerstein and his co-workers (2), (3).

(b) Gowin's Vee heuristic and concept mapping as means of establishing the relationship between the conceptual and procedural components of the structure of knowledge (5), (6)

We shall first consider the Feuerstein approach and present some research results in physics germane to the field of misconceptions and other analyze Gowin's approach with relevant research material from mathematics.

Feuerstein's Approach

The learning modality from a Piagetian perspective is Stimulus-Organism-Response. The organism in responding to and reacting with the stimulus impinging upon it, undergoes a learning experience dependent on its level of development. In this manner, cognitive structures are built up. Feuerstein and his co-workers at the Hadassah-Wizo-Canada Institute in Israel (2) see the need to add a second modality: Stimulus-Human-Organism-Response. This is based on an interesting psychosocial theory call Mediated Learning Experience. They claim that a lack of the proper mediation of the world to the child by the primary mediators, parents, and secondary mediators such as teachers, leaves the child with deficient cognitive functions. It is claimed that because of such deficiences disadvantaged students have so much difficulty in pursuing the usual academic curriculum. Over a period of 20 years of observation of disadvantaged Israelis from disparate geographical backgrounds using a clinical device called the Learning Potential Assessment Device, they have developed a model of thought processes which they call the Cognitive Map. One of the seven parameters of the Map is the Phase of the mental act divided ino three phases for purposes of convenience:

(i) Input. This relates to the quality and quantity of the data selected as a person attempts to solve a problem.

(ii) Elaboration. This involves the way in which the available data is used in reaching the solution of the problem.

(iii) Output. This affects the ability to communicate the results of a particular elaborative process.

Based on their observations, Feuerstein et al have identified the following deficient cognitive functions in disadvantaged students:

[Slides 1, 2 and 3]

It is clear that if students have some of the deficiences listed here, they will indeed have significant difficulties in dealing with physics and mathematics especially as related to their ability to solve problems.

The research conducted in the Physics Department at University of Western Cape represented an effort to establish whether the students did indeed show deficiences in their cognitive functioning and to examine methods of addressing these problems.

The first cognitive function looked at was the ability to plan in using physics concepts (elaboration). The subjects of the study were all first year university students, i.e., students who had finished school. Since Newton's three laws would have been done in some detail with all these students at school, they were tested on their ability to use some planned approach in using these concepts. A paper-and-pencil test is administered to all incoming students to determine whether they recognize details of Newton's laws especially in solving problems, which could indicate that they have some procedure which they bring to bear in using the laws. The results indicate not only an inability to solve a simple equilibrium problem, but also confusion as to which law applies to what situation as well as a lack of recognition of important features of the law. For example less than 10% of students draw correct forces on a particular system in dealing with Newton.

In trying to determine whether students are able to extract numerical data from a problem formulation accurately, whether the data implicit in a problem is meaningful to them and whether they are able to visualize physical situation described with words but no sketches, it was decided to employ the individual interview technique. The student is given a problem, asked to read it through carefully and then to write down all the data he/she is able to extract from it. Attempts are made to probe their understanding of words and ideas in the problem and to examine how they use the data they extract to attempt to solve the problem. When these interviews were conducted, all the students had already covered the material in the lectures. The two problems given are the following: [Slide 4].

From the protocols which resulted, it appears that the students seem to have difficulty in analyzing data in well-defined, ordered manner. Some of these are the following:

1. They seem unable to visualize clearly the physical situation described in the problems. This was reflected not only in their difficulties with verbal description, but also in the lack of clarity of detail of many of the sketches attempted. Indeed, the majority drew sketches only after prompting.
2. No real need was perceived to make a qualitative evaluation of the problem situation. Students seem to focus on the numerical data followed immediately by efforts to use it in equations.
3. Implicit data in the problem is not easily or automatically made explicit. Although some had no difficulty in relating s and t for the two bodies in problem 1 (although some did) the majority experienced difficulties in problem 2 where relationships have to be established.

4. The actual problem is not readily defined by some. Thus equations are used in the hope that the answer will "fall out."
5. Students tend to focus on each object separately and to examine the data of each independently.

Overlapping of the interviews with the list of cognitive deficiencies on input given by Feuerstein, indicates the following cognitive deficiences in the students:

(a) Blurred and sweeping perception.
(b) Unplanned, impulsive and unsystematic exploratory behavior.
(c) Lack of precision and accuracy.
(d) Impaired use of two or more sources of information.

[Slide 1]

While more work needs to be done to determine how pervasive and deep-rooted these deficiences are the interviews provided an interesting insight into the actual difficulties which students experience as they approach a piece of physics content.

Note, how the input function are relevant if examination-type questions are used to test misconception. The following question comes from a test designed by Helm (4):

⟶ ·
(1) (2)

Particles (1) and (2) are a long way from the rest of the universe but quite close to each other. The mass of particle (1) is half that of particle (2), and the two particles exert gravitational force on each other. If the arrow above represents the force exerted by (2) on (1) in magnitude and direction, which ONE of the following arrows represents the force exerted by (1) on (2)?

(a) ← (b) → (c) ⟶ (d) ⟵

Considering the amount of data that has to be sifted through, the decision that must be made of the concept to use, the planning procedure that needs to be applied to use the concept decided upon, it is clear that more is required than the simple knowledge that "to every action there is an equal but opposite reaction."

The above is not to be understood as implying that misconceptions do not exist. They are obviously alive and well! However, the point being made is that the origin of the misconceptions as well as our view of how pervasive they are, need to be influenced by our analysis of the task structure established to test their existence. Clearly, the simple problem-solving type of procedure is fraught with cognitive difficulties.

An identification of weaknesses in students' cognitive processing will thus act as an inhibitor in labelling misconeptions as an all-pervasive indication of students' understanding of a particular area of content. It also does not indicate that students' in correct views of the world are necessarily very deep-rooted. They may well be, but until some of the ambiguities of what exactly causes the misconcpetions are eliminated, there can be no certainty in this regard. It implies that in giving instruction, great care needs to be exercised in supplying "ancillary knowledge." Instructors need to be aware of how much, apart from pure content, is involved in internalizing a particular idea, i.e., the process needs as much attention as the product.

If this view is held, then we will be concerned not merely with how knowledge of misconceptions can influence instruction, but also how the recognition and implementation of necessary strategies for teaching the relevant processes in effecting a particular product, will affect misconceptions.

Gowin's Approach

For Gowin (5) the central concept in the educating process is *meaning*. He defines educating as "changing the meaning of human experience" and not merely changing behavior. Meaning is a social phenomenon and can therefore be shared. Teaching then becomes the achievement of shared meaning and learning is the deliberate act of re-organizing an existing pattern of meaning after new meaning is grasped. Gowin proposes four commonplaces which should be present in an event for it to be an educative event: the teacher, the learner, the curriculum, and the social context in which the event takes place. Education causes people to come into possession of their own powers and also helps students to integrate their thinking, feeling and acting. Gowin's theory ties in very well with the Ausubel-Novak (7) theory of meaningful learning.

During the summer of 1982, 25 South African students were given a 5-week orientation course in college Algebra and Trigonometry. Most of these students had indicated that they disliked or feared mathematics and had no confidence in their own ability to understand mathematical problems. They came from a background in which they could perform satisfactorily in an essentially rote learning mode since very little instruction for meaningful understanding is given by the largely under-qualified high school teachers in South Africa.

Very early during the course, students were encouraged to identify key concepts. These were to be distinguished from algorithms and other types of procedural knowledge. By using organized and unorganized lists of words from everyday life, it was demonstrated to the students that there is much virtue in organizing knowledge for meaningful learning. Students were then introduced to the two-dimensional nature of concept maps by drawing from examples in science (e.g., the nature and production of sound). Special emphasis was placed on the propositional relations among concepts and on hierachical structure. At the end of the first week the class constructed a joint list of major algebra concepts which were encountered during the lectures of that week. The students were then asked to construct their own concept maps using all or some of the concepts on the list. On subsequent weeks students were required to construct their *own* list of concepts, re-arranging these concepts in a hierarchical manner and then draw their concept maps for the work covered during that week. The concept maps were considered as the take-home portion of the weekly class test.

The first point of interest was how this meaningful learning approach would affect the students' perceived attitude towards mathematics. Coming from a society in which they were subjected to predominantly authoritarian instruction, students were initially apprehensive at the new idea of identifying concepts rather than merely looking for procedures. However, the students soon got accustomed to the idea and by the end of the second week they could very easily list the major concepts after each lecture. They found this exercise very exciting and meaningful. One major advantage of the concept map was the opportunity it created for dialogue between instructor and student. The students found the first map particularly hard but subsequent maps were constructed with less difficulty. During diagnostic discussions with individual students, they were asked to explain the links and hierachy of their maps. This disembedded some misconceptions which could then be addressed in a remedial way. Some of these were *semantic* misconceptions, i.e., A stands for C and not for B and should be the case. An example: a student asserts that a logarithm is a base of a power -- here the students tenaciously insists on the correctness of the assertion even after teacher probings and so it is more than a mere oversight or careless error. Other misconceptions were *syntactic* in nature, i.e., it was clear from the concept map that the student either links the concept in an incorrect manner with other concepts or fails to see any connection between the concept and other concepts. Some maps were clearly devoid of meaning which is apparent from the meaningless links between concepts and lack of hierarchical structure. Generally mathematics had become more than a fixed set of facts and rules which had to be learned and later reproduced but was otherwise beyond inquiring and largely meaningless. Many of the students expressed the feeling that mathematics had taken on a new meaning for them and that they had developed a greater confidence in their own ability to understand mathematics.

One point of concern that came out of this study was the lack of procedural efficiency displayed by some of the students even after they have identified the key concepts and could link them in a meaningful way to form a concept map. This question was probed further in a subsequent study which involved 16 Cornell University calculus students all of whom had completed at least one semester course in calculus. During clinical interviews students were first questioned about their command of the key concepts as identified by their instructors and as suggested from the course material. These concepts were:

(a) notions of rate of change
(b) the idea of infinitesimal rate of change which then involves the idea of a limit and the notion of a derivative.
(c) the concept of linear approximation
(d) the idea of error analysis
(e) integration as a *continuous* sum.

After establishing what students knew and also identifying some semantic and syntactic misconceptions the students were asked to reflect aloud about the following two problems: [Slide 5]. The students had previously encountered these problems in a class test which they took 4 to 5 months earlier. The first problem involved the idea of integration as a continuous sum. Those students who thought of integration only as the inverse operation to differentiation could not give any indication of how to answer the question. Besides the minor misconception of confusing circumscribed and inscribed rectangles, the most common misconception here was the idea of integration as a discrete sum. Most of the students who had command of the correct concepts could do the problem even though it was accomplished with less efficiency. However, there were some students who could not do the problem although they showed a clear command of the concept of integration and of limits. This was the first suggestion that a mathematical concept involved more than an idea but that the concept was inextricably bound up with the procedure. The concept of limit needed to be discussed in a procedural way both in relation to derivatives as well as integrals.

This notion was reinforced when students tried to discuss the second problem. The reaction of most students was: "I can't do it, there's no way in which I could remember how to do this problem... I've forgotten how to do it." However, again those who had indicated earlier in the interview that they knew what a derviative and related concepts such as zero rate of change were, could after probing, discuss the problem quite easily conceptually. Again, those who could think only in terms of procedures had forgotten the procedure and could not discuss the problem at all. It was observed here once again that some students who had the necessary concepts could not successfully solve the problem becaue of a lack of procedural knowledge.

It is important therefore to note that the conceptual part of mathematics is linked to the procedural part of mathematics through the formal structure and symbolism of the subject. An operational symbol such as "+" invokes both a concept [or many concepts] and a procedure. During instruction it is important for the teacher to realize that in mathematics the procedure is intrinsic to the concept. When we teach the concept we should indicate that this also involves a procedure.

It is at this point where Gowin's Vee heuristic has proved to be a very useful device in analyzing the structure of knowledge in any discipline.

[Slide 6]

It indicates how the conceptual and methodological aspects of a discipline are related. It suggests an event sense of educating -- an event involves process as well as product. A Cornell graduate student has constructed the following Vee map and concept map for a simple problem in analytical geometry.

[Slides 7 and 8]

We would like to suggest that misconceptions involve both sides of the Vee and would normally have its origin at the bottom of the Vee. Misconceptions are not normally deep-rooted alternative world views but is confined to conceptual (i.e., semantic and syntactic meanings) and procedural considerations and can best be addressed by giving attention to both conceptual and procedural aspects of mathematics.

A word of caution may be in order here. We believe that the reason why mathematics has become so particularly threatening to so many students is that their own perception, judgment and insight are overridden by the teacher's demand for convergent thinking. The notion that there could only be one correct answer to any mathematical problem has led many students to question their own experience and perception of reality and consequently destroyed their confidence in their own way of thinking. In mathematics, perhaps more than in any other subject there is a tendency on the part of teachers to teach by assertion rather than by agreement. The acceptance of meaningful material depends on its integration into, and reconcilliation with a prior cognitive structure which in turn expands the students' own perception and understanding of reality. It must be understood that meaningful learning cannot take place unless the concepts are made accessible to the students. We have attempted to point out that in mathematics and physics the concepts also imply procedures. These procedures are derivative from the concepts and are subsumed by them. [Slide 8]

In order to address misconceptions we need to reintroduce an event-sense in our instruction. Both Feuerstein's and Gowin's theories give attention to this need. We have pointed out that a misconception is as much a process as it is a product and cognitive instruction such as suggested above could be a very effective means of analyzing and alleviating the cognitive deficiencies and faulty conceptual structures of students.

OUTPUT PHASE

1. EGOCENTRIC COMMUNICATIONAL MODALITIES
2. LACK OF, OR IMPAIRED, VERBAL TOOLS FOR COMMUNICATING ADEQUATELY ELABORATED RESPONSES
3. LACK OF, OR IMPAIRED, NEED FOR PRECISION AND ACCURACY IN COMMUNICATION PROCESSES

PROBLEMS

#1. AT THE INSTANT THE TRAFFIC LIGHT TURNS GREEN, A CAR STARTS WITH A CONSTANT ACCELERATION OF 2 M S^{-2}. AT THE SAME INSTANT A LORRY, TRAVELLING WITH A CONSTANT SPEED OF 10 M S^{-1} PASSES THE CAR.

(A) HOW FAR BEYOND THE STARTING POINT WILL THE CAR OVERTAKE THE LORRY?

(B) HOW FAST WILL THE CAR BE TRAVELLING AT THAT INSTANT?

#2. A LIFT, HEIGHT 3 m, ACCELERATES UPWARD AT 2 M S^{-2}. AT THE INSTANT THAT ITS VELOCITY IS 2 M S^{-1}, A SCREW FALLS FROM THE ROOF OF THE LIFT. CALCULATE:

(A) HOW LONG THE SCREW WILL TAKE TO REACH THE FLOOR

(B) WHAT DISTANCE IT THEN HAS FALLEN.

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DEFICIENT COGNITIVE FUNCTIONS

I

INPUT PHASE

1. BLURRED AND SWEEPING PERCEPTION
2. UNPLANNED, IMPULSIVE, AND UNSYSTEMATIC EXPLORATORY BEHAVIOUR
3. LACK OF, OR DEFICIENT NEED FOR, PRECISION AND ACCURACY IN DATA GATHERING
4. LACK OF, OR IMPAIRED, CAPACITY FOR CONSIDERING TWO SOURCES OF INFORMATION AT ONCE

ELABORATIONAL PHASE

1. INADEQUACY IN EXPERIENCING THE EXISTENCE OF AN ACTUAL PROBLEM AND SUBSEQUENTLY DEFINING IT
2. INABILITY TO SELECT RELEVANT AS OPPOSED TO IRRELEVANT CUES IN DEFINING A PROBLEM
3. LACK OF SPONTANEOUS COMPARITIVE BEHAVIOUR
4. LACK OF, OR IMPAIRED, PLANNING BEHAVIOUR
5. EPISODIC GRASP OF REALITY

Problem 1: The stiffness of a rectangular beam is proportional to the product of its breadth and the cube of its depth. Find the stiffest beam that can be cut from a log of a given diameter, d.

Problem 5. Using the definition and circumscribed rectangles, find the area under the curve $y = f(x) = x^2+1$ from $x = 0$ to $x = b$.

You might find the following useful.

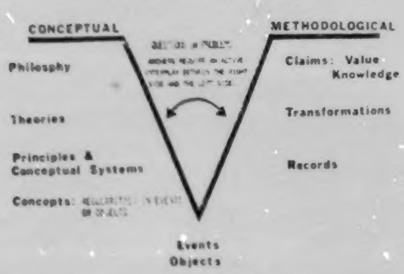
$$1+2+\ldots\ldots+N = \frac{N(N+1)}{2}$$

$$1^2+2^2+\ldots+N^2 = \frac{N(N+1)(2N+1)}{6}$$

$$1^3+2^3+\ldots\ldots+N^3 = \frac{N^2(N+1)^2}{4}$$

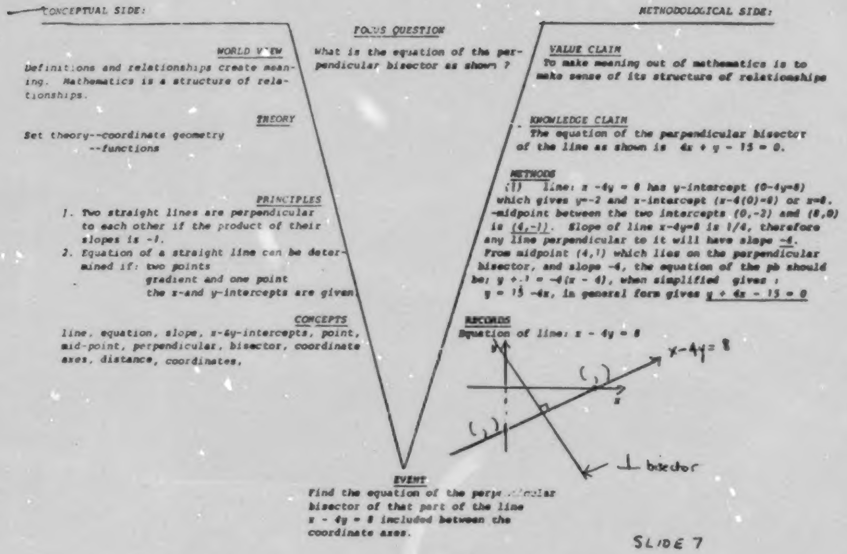
SLIDE 5

GOWIN'S EPISTEMOLOGICAL V


CONCEPTUAL
METHODOLOGICAL
Philosphy
Theories
Principles & Conceptual Systems
Concepts:
Claims: Value Knowledge
Transformations
Records
Events Objects

Gowin's Vee heuristic showing the key elements involved in the construction of knowledge. In the process of knowledge construction, every element interacts with every other element, although much research and routine scholarship does not consciously involve conceptual-theoretical elements in the process of knowledge construction.

SLIDE 6



CONCEPTUAL SIDE:

WORLD VIEW

Definitions and relationships create meaning. Mathematics is a structure of relationships.

THEORY

Set theory--coordinate geometry
--functions

PRINCIPLES

1. *Two straight lines are perpendicular to each other if the product of their slopes is -1.*
2. *Equation of a straight line can be determined if: two points*
   gradient and one point
   the x-and y-intercepts are given

CONCEPTS

line, equation, slope, x-&y-intercepts, point, mid-point, perpendicular, bisector, coordinate axes, distance, coordinates.

FOCUS QUESTION

What is the equation of the perpendicular bisector as shown ?

METHODOLOGICAL SIDE:

VALUE CLAIM

To make meaning out of mathematics is to make sense of its structure of relationships

KNOWLEDGE CLAIM

The equation of the perpendicular bisector of the line as shown is $4x + y - 15 = 0$.

METHODS

(1) line: $x -4y = 8$ *has y-intercept* $(0-4y=8)$ *which gives* $y=-2$ *and x-intercept* $(x-4(0)=8)$ *or* $x=8$. *-midpoint between the two intercepts* $(0,-2)$ *and* $(8,0)$ *is* $\underline{(4,-1)}$. *Slope of line* $x-4y=8$ *is* $1/4$, *therefore any line perpendicular to it will have slope* $\underline{-4}$. *From midpoint* $(4,1)$ *which lies on the perpendicular bisector, and slope -4, the equation of the pb should be:* $y +.1 = -4(x - 4)$, *when simplified gives :* $y = 15 -4x$, *in general form gives* $\underline{y + 4x - 15 = 0}$

RECORDS

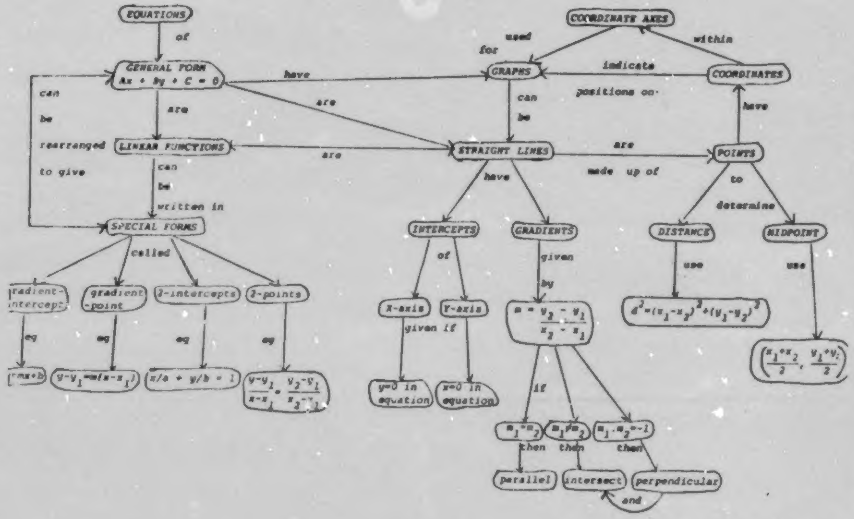
Equation of line: $x - 4y = 8$

y
x
x-4y = 8
(,)
(,)
⊥ bisector

EVENT

Find the equation of the perpendicular bisector of that part of the line $x - 4y = 8$ *included between the coordinate axes.*

SLIDE 7


EQUATIONS
of
GENERAL FORM Ax + By + C = 0
have
are
can be rearranged to give
are
LINEAR FUNCTIONS
are
can be written in
SPECIAL FORMS
called
gradient-intercept
gradient-point
2-intercepts
2-points
eg
y=mx+b
y-y1=m(x-x1)
x/a + y/b = 1
(y-y1)/(x-x1) = (y2-y1)/(x2-x1)
COORDINATE AXES
used for
within
GRAPHS
indicate positions on
COORDINATES
can be
have
STRAIGHT LINES
are made up of
POINTS
have
INTERCEPTS
of
X-axis
Y-axis
given if
y=0 in equation
x=0 in equation
GRADIENTS
given by
m = (y2 - y1)/(x2 - x1)
if
m1=m2
m1≠m2
m1.m2=-1
then
parallel
intersect
perpendicular
and
to determine
DISTANCE
use
d²=(x1-x2)²+(y1-y2)²
MIDPOINT
use
((x1+x2)/2, (y1+y2)/2)

CONCEPT MAP OF THE PROBLEM

SLIDE 8

RESEARCH METHODOLOGY IN INVESTIGATIONS OF STUDENTS' CONCEPTIONS IN SCIENCE

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INTRODUCTION

This paper will discuss some of the research methods, assumptions, difficulties, and pitfalls involved in investigations of students' conceptions in science. It will consider implications for research design and interpretation of response data.

The methods used for investigating conceptions include: written tests (both free response and multiple-choice); clinical interviews of various types; and tutorial dialogue in teaching situations.

I have some conflict in discussing research methodology and validity in this area: from one viewpoint, I wonder how much it matters; perhaps the more important thing is simply that awareness of the existence of alternative conceptions becomes widespread, with some knowledge of the variety encountered in a particular field, so that teaching practice may take it into account. The details pertaining to the specific teaching situation could be further elucidated in actual practice. On the other hand, one would wish investigations to meet some of the criteria of good research work in the social sciences, so that the validity of the findings is not uncertain due to methodological flaws, and so that possibly erroneous conclusions and interpretations can be avoided.

Curiously, some of the more casual research methodology has been used by some investigators with backgrounds in the "hard" sciences, such as physics. Methods, precautions, and controls of research in the social sciences have often been lacking, or possible confounding factors not recognized. On the other hand, investigators expert in the subject matter have the advantage of good understanding and insight into the specific situations used.

Whether methodology is an issue also depends on the objectives of the work. For instance, one aspect of the initial studies of several investigators of concepts is simply to generate, from open-ended, not too carefully specified everyday situations and questions, as wide a range of responses and conceptions as possible. Other workers, such as McDermott and co-workers[1], have done careful empirical work, using very simple basic situations, real observed systems, operational definitions of concept understanding, and detailed probing of student thinking by interview.

DISCUSSION OF VARIOUS FACTORS INVOLVED IN INVESTIGATIONS OF CONCEPTIONS, INCLUDING ASSUMPTIONS, DIFFICULTIES, PITFALLS AND PRECAUTIONS

The abstract above lists various factors involved and difficulties encountered in the investigation of conceptions. These will now be discussed. Some of the items may overlap to a considerable extent, so I will not attempt to treat them exactly item by item, and I also hope the reader will excuse some repetition.

Confounding factors. Everything is complex, interlinked and partly subjective in this field. Conceptions, or cognitive frameworks, are complex; the situations and questions posed are more complex than usually realized; many interacting factors may be involved simultaneously; context plays an integral part; and interpretation is inherent.

Because of the complexity, and because it is useful to conduct studies in reasonably realistic contexts, it is inevitable that many extraneous factors

will exist that can affect the study. If possible these factors should be taken into account; perhaps some of them can be controlled, avoided, allowed for, or simply acknowledged. It may be difficult to control for many of the possible influencing variables; few studies thus far have attempted to do so, and not all have explicitly acknowledged their existence.

Possible effects of the theory-base, assumptions, expectations, prejudices and subjectivity of the investigator. The role and effect of the investigator is probably inherent and unavoidable in this field. It becomes hard to hold a point of view that studies are discovering definite "objective facts" about students, which exist independently "out there."

The investigator may act, in part, as the poser of the research question, designer of the study (including methods used and questions posed), the data-gathering instrument, the analyzer and interpreter of data, and the synthesizer of conclusions and models. The theoretical leanings, expectations, assumptions (implicit or explicit), expertise, approach and subjectivity of the investigator will play a part in all this. The investigator is not a totally objective mechanical data gatherer and analyzer. The responses *mean* something to him or her. They are not simply recorded in a vacuum, but almost automatically processed and interpreted as to their possible meaning and implications. The investigator, after all, is trying to make sense of the investigation, just as the student is doing for the problem presented. Investigators' interpretations of what they hear can be influenced by their own understanding of the problem, by what they expect to hear, by similarity to previous cases, by selective attention, etc. Two investigators with different theoretical models in mind might reach different conclusions from the same data; but then it is unlikely they would even obtain the same data because they would structure the procedure and questions differently.

Of course, all this does not *necessarily* mean that two independent investigators are completely unlikely to produce similar findings. Perhaps I have overstated the subjectivity aspect somewhat in order to make the point; of course, one hopes (and works on the assumption) that everything is not hopelessly relative and subjective, and that two different investigators can obtain similar or comparable findings by using precautions and taking account of difficulties.

As an example of the role of the investigator's research ideas, consider the investigator's conception (!) of the nature of conceptions. If a concept (such as force) is viewed as a straightforward, definite, and even independent "entity", then a few instances and responses may prompt the investigator to categorize the subject as (say) "Aristotelian" as regards understanding of motion and force. If on the other hand, an investigator views a conception as a multi-faceted cognitive framework or interactive network of interlinked knowledge and ideas, then both the research design and the findings are likely to be very different from those of the previous investigator.

Choice of research paradigm can similarly affect studies; adoption of a natural-sciences paradigm involving indentification, isolation and control of variables will probably produce a different product from an holistic paradigm[2], where a complex interactive system is studied in context, and the focus of the study may develop during the course of the work.

Similarly, two very different approaches reflecting different outlooks are the application to a large population of a few questions via questionnaires with statistical analysis of brief responses, or the probing in depth of the thinking of a number of individuals, over a range of different questions.

Unrecognized complexities underlying apparently simple physics problems. Presumably, when we start investigating conceptions, we might choose first to present very basic, simple situations, without too many things going on at once. Unfortunately, some apparently "simple" situations are far more complex than may initially be realized by the investigator, both as regards detailed features and ancillary concepts and knowledge required.

As an example, consider the "simple" pendulum. The student may be asked to specify the forces acting on the pendulum bob at various points of the motion. In fact, this system is not really simple, possibly even to the physicist. There are indeed just two forces acting on the bob (if friction is neglected), but both the direction and magnitude of one is changing, while the other remains constant, and the relative direction between the two varies. Not only does the direction of motion change continuously, but also the speed; there is both "centripetal" and tangential acceleration, neither of them constant. There are several distinguishable phases of the motion, e.g. where the resultant force is roughly with, or against, the direction of motion, or where the velocity is zero. The resultant force also varies continuously in both magnitude and direction (as does the velocity) but is not along the path of motion, though enough so to possible confuse.

Now if a student draws in a tangential force along the path of motion, what can we conclude? That the student believes that motion requires a force in that direction? That the student is "Aristotelian"? Perhaps. But on the downward swing, there is, after all, acceleration along the motion, and does not acceleration imply a force? So in a sense, there *is* a tangential force along the path in this (complex) situation, albeit a "component" force (though not identical with the "resultant" force!). The above has been a physicist's perspective; how might the student see it? With all these subtleties present in the situation, it is hard to draw valid conclusions. It would be preferable to choose simpler problems.

Other situations, such as trajectory motion, or rockets in space, have their own difficulties, which one should at least be aware of.

Need to clarify underlying concepts. As my first project in this field, I initially decided to investigate students' understanding of basic dynamics, in particular Newton's Second law, F = ma. Almost immediately it became apparent that the separate underlying concepts, force, mass, and acceleration, were both ill-defined and ill-understood in the students' minds, and the work became instead an investigation of their conceptions of "force" in dynamics.[3] Students' conceptions and reasoning processes concerning a principle, in this case the relationship between force, mass, and motion, cannot be studied independently of their notions of the underlying concepts involved. Tacit unchecked assumptions that underlying concepts and words are used in the accepted scientific sense will make for meaningless findings, especially from questionnaire-type tests.

Semantic difficulties. To what extent are apparent misconceptions matters of semantics? This is an inherent and serious difficulty, more so in some topics than others. In mechanics, the problem may be particularly severe, since the phenomena and words involved (such as force, speed, mass, acceleration, momentum, energy, etc.) are common to everyday experience and everyday language.

The words used may have fuzzy, not clearly defined meanings to the student. They may not always be differentiated from related terms. There may be multiple meanings, and situational meanings which change with context. Even within a single situation or even a simple sentence, the same word (e.g. "force") used twice may actually correspond to two related but not identical conceptions in the student's mind. The words used may thus have different meanings to student and investigator.

Thus there are pitfalls in accepting any statement at face value, and drawing conclusions without further probing. This is a particular danger in written tests. A student's usage of terms may not correspond very well to either the accepted scientific meanings or to the actual conceptions in the student's mind.

Students' conceptions and usage of "force", for example, seem to a fair extent to be mixed upwith, and undifferentiated from, concepts resembling impulse, momentum, impetus, inertia, or energy, etc., depending on the context. In fact, in many situations, if the word "force" in the students' explanations is appropriately replaced by "impulse" or "momentum", the explanations can often make reasonably good scientific sense, although initially they may have been labelled "misconceptions".

Meanings should therefore be inferred from context and usage, whatever the words used. In this regard, clinical interviews, allowing for clarification and elaboration, are probably essential. Note that the device of asking the student to define terms is quite inadequate, although of interest. Unchecked assumptions that the words are used with the accepted meanings may thus invalidate conclusions. In this regard, one may imagine replacing the word force by "force" or even "force (?)" where appropriate in a published study.

One method of clarifying semantics in an interview is to substitute a more explicit phrase for the word, and see if the response changes. For example, after asking: "Are there any forces on the object?", one may later ask: "Is there anything pushing or pulling on the object *now, here*?" This phrasing limits the student to the desired scientific meaning of the term, and it is not unusual that the answers to the two questions differ. For example, students who claimed that there was a force on a frictionless puck moving at a steady speed, usually responded, "no" to the rephrased question. Further discussion revealed that some students originally meant "the push you originally gave it to get it started," and others meant something related to momentum, but they did *not* mean that there was a force in the *scientific* sense on the puck at that moment.[3]

Thus it may be that the student's reasoning is not unsatisfactory, but his or her usage of terms is incorrect. Thus semantic considerations can be crucial, and "misconceptions" may not be what they seem. Lewis Carroll's Humpty Dumpty explains to Alice that when he uses a word, it means exactly what he wants it to mean.

One aspect of demonstration interviews involving real observed situations, is that the student may indicate his or her ideas by actions or demonstration, as well as language. This may alleviate a part of the semantic difficulty, but only a limited part, since in cognitive studies we are concerned with the underlying *reasoning*.

It may be of interest that from interviews on students' conceptions of force in dynamics, it seemed that a prevalent conception employed was more related to what we would call "impulse" than to the accepted scientific meaning of the concept force. Symbolically, one might say that many students seemed to employ something like $\int Fdt$ rather than F, for situations involving motion. (One might speculate as to why this should occur. Possibly because force (F) is an instantaneous or differential concept in a motion, while impulse $(\int Fdt)$ is an integral concept, taken over an observed period of the motion. Possibly in our perception of the world, we more readily observe and experience the integrated effect of a force rather than an instantaneous quantity. It is interesting to note that Newton's second law was originally formulated in terms of change in the quantity of motion, rather than acceleration, and that perhaps the reason we usually use the differential form is because forces that are directly calculable from force laws.)

Need for sufficient depth and breadth of probing in elucidating cognitive frameworks. If conceptions involve multi-faceted, complex, interaction cognitive networks, linking many items of knowledge and experience, and if alternative types of knowledge and conceptions co-exist, then to properly elucidate the nature of an individual student's conceptions and thinking necessarily requires probing in considerable depth, and also over a wide range of situations in which the conception is used.

Furthermore, if conceptions are also constructive, in that they involve an on-going process of making sense of situations, then they are not static but may be modified and to some extent even "put together" in the process of considering a situation or problem, particularly if it is somewhat unfamiliar.

On this view of the nature of conceptions, insufficient depth and range of probing cannot produce a satisfactory representation of an individual's schemata. Findings might characterize a student's responses in a limited context, but that is all that could be said. It is granted, however, that this is valuable in itself. However, there is a tendency to then over-generalize the results.

Erickson[4] suggests that one can view each question posed in a detailed investigation of an individual's thinking as a particular stimulus in a particular context, which may bring forth a particular conception or aspect of a conceptual map. This might be likened unto a revealed "cross-section" of the conceptual structure, using a particular conceptual "slice". Moreover, it is probed at a particular time in the history and development of the individual's conceptions, so one might also draw a "snapshot" analogy. Of course, to investigate the development with time of conceptions is a formidable task.

Premature and over-general conclusions and categorizations. There are several aspects, as mentioned in the following paragraphs.

There is a particular danger in this regard from written tests, or from the presentation of single instances to students, or from the acceptance at face value of initial responses. The course of an interview in some depth will make this danger apparent; initial responses and meanings become clarified on further discussion, and this can often completely change one's initial interpretation or conclusion.

Matters of semantics need to be identified, or conclusions about students' misconceptions may be drawn from evidence which really bears more on their usage of terms.

To make inferences and draw conclusions about students' conceptions and thinking without actually probing their reasoning for responses is a dubious endeavor. Any interviewer will recall numerous cases where the reasoning offered for a particular response came as a complete surprise, often after the interviewer had already tacitly mentally categorized the student in some way which might fit a presumed hypothesis.

Just as initial responses can sometimes be misleading, so can more detailed questioning if confined to a single situation or instance. One instance, or even a few, is hardly satisfactory to map out a conception, or rather framework, which is probably complicated, multi-faceted and contextual. Moreover, students' conceptions are often situation-bound, produced in an ad hoc fashion to account for particular situations. This is in contrast to scientific concepts, which are not intended to be situation-specific, but to be generally applicable to all situations in a domain. Guesne[5] has noted the influence of situation, method, and probe of reasoning on the results. I believe Goldberg[6] and McDermott have suggested an operational definition of "holding" a conception as being the consistent application of the same idea throughout an interview, and also throughout a range of different situations.

A related danger is that of too readily assigning *labels* (such as "Aristotelian") to particular students or groups of students. While labels or terminology can be useful in organizing ideas in a field, they can also become blinkers or straitjackets to creative thinking or alternative interpretations, particularly if they are overly simplistic, or even inappropriate.

Difficulties related to the nature of conceptions. Concept modification and learning during the investigation. The complex nature of conceptions or schemata makes them hard to investigate and characterize. Previous sections have already discussed the nature of conceptions and the consequent difficulties in investigation. As far as interpretation and conclusions are concerned, the nature of conceptions warns that one should not too readily assign definite conceptions to students unless one is sure that the conceptions are definite!

Perhaps it may seem a less satisfying research outcome to say that conceptions (such as "force") are often a vague and loosely-held mixture of ideas, resembling but not well-differentiated from formally-defined physical concepts such as force, impulse, momentum, energy, inertia, etc., but this outcome may be more realistic than trying to identify a distinct, well-developed, firmly-held alternative system of beliefs, unless the latter conclusions is based on a broad range of detailed and consistent evidence.

Concept modification or learning during the investigation is continuously observed in interviews, particularly demonstration interviews involving real phenomena, where students' predictions can be tested against their observations. In one sense this might be considered a research difficulty, if we had wanted to find out what the "existing" conception was. In another sense, it gives a more realistic picture of the students' thought processes. Often, particularly in the pre-instruction case, the student may simply not previously have had the occasion to give a particular situation careful or explicit thought before the question was posed in the investigation. Ideas will then crystalize during consideration of the question, as thought and knowledge is brought to bear. Conceptions, being interactive with the world, are affected by the enquiry and by the concentration of the mind on the situation. If, in addition, fairly unfamiliar situations are used, it may be that we will be studying not only "existing" conceptions, but the putting together or construction of conceptions, i.e. the expansion of a conceptual framework.

Effect of the particular situation, presentation, and formulation chosen. The situations chosen, the way they are presented, and the way the questions are formulated can make a difference. Even apparently minor differences in wording, phrasing or order of presentation can have an effect. The way a description or question is worded can emphasize or de-emphasize certain features of the situation. Certain aspects can be made explicit, left implicit, or avoided altogether by choice of formulation or wording. The way vectors are drawn on a diagram might tend to encourage or discourage a particular line of thought or misconception. Alternatives may be presented in an unwittingly biased fashion. Experience, awareness, and attention to detail are needed to deal with these potential pitfalls.

In written questions, the formulation is fixed. In interviews, there is flexibility to clarify or reformulate as the interview proceeds. Yet even in interviews, the mode of presentation can be significant. Even in demonstration interviews involving real observed situations, particular features which are perceptually obvious may tend to attract undue attention.

Various features of presentation or formulation which may affect results are noted briefly as follows. A situation may seem to a student to require fairly prompt answers rather than prolonged thought or analysis. The investigator needs to distinguish between spontaneous responses and the ability to think things out and marshall information. Very familiar situations and less familiar situations involving the same concept will involve different mental processes. The same problem presented in writing or verbally, or diagrammatically or by real demonstration may not generate identical responses. Viennot[7] has noted that similar problems presented in either the 'forward' or 'reverse' direction can evoke different conceptions.

The psychological and social 'demand characteristics' of the investigation situation, and perceptions of the nature and requirements of the investigation. There are various factors, extraneous to the cognitive objectives of the study, which may affect the behavior and responses of the student. The so-called demand characteristics of the situation in which the students (and indeed the investigator) find themselves, will influence them. Factors such as personality, psychology, social conditioning, cultural background, experience, mood, state of mind, emotion, attitude, surroundings, etc., may each play a role, to a greater or lesser extent, for both the student and the investigator.

Different students, or the same student given different situations, times, environments or investigators, may be nervous or relaxed, confident or self-doubting, able to concentrate or self-conscious. It is well known that some good students can go to pieces in an oral examination, and for this reason, the results are often considered unreliable. The same is true to a lesser extent of written examinations. Will the student perceive our investigation in the same way, or will an explanation of its purpose alter this?

The perceived character of the investigator will influence interaction with students. Investigators may come across as having (for example) some of the following attributes or their opposites: businesslike, friendly, impatient, remote, relaxed, judgmental, etc. It may also matter whether a student sees a particular investigator as closer to an instructor or a peer.

Cultural and social factors, and the perceptions of students as to what is expected of them, are also involved. For instance, years of schooling might have conditioned some students to "search their memories" for the "correct answer". Such students may not consider their own reasoning valuable. In some cultures more than others, there is a desire to give answers which will please the listener. Students may tell you what they think you would like to hear. Also, if you are the physics teacher, you may tend to evoke somewhat more of a physics mode of answering than might otherwise be the case.

McLelland[8] suggests that the institutional environment often involves deference to instructors and a tacit requirement on the student to come up with *some* answer. They may be reluctant to admit lack of understanding, or to appear stupid. Such social pressures can sometimes make responses virtually meaningless for our purposes.

It is therefore important that the nature and purpose of the investigation, and what is required, be carefully explained to the student. The students should realize that it is their thinking that is of interest, rather than any 'right' answers.

One hopes that despite these influences and difficulties, one will still be able to obtain a reasonable picture of a student's cognition. Human judgment, awareness, experience, etc., will be involved in determining what is going on, weighing the various factors, and making inferences. The situation is probably not as uncertain, subjective and difficult as may appear from the discussion in this paper; the purpose here has been to focus on and emphasize confounding factors and points of difficulty. However, many of these can to a reasonable degree be dealt with, controlled, eliminated, allowed for, or acknowledged. To do this, however, one must at least be aware of them, so that precautions can be taken.

Cues, prompting and suggestibility in interviews. Attention needs to be paid even to small details in an interview. There may be unwitting leading phrasing, cues, prompting, or reactions which the student may pick up. The way something is phrased, or the tone of voice, may encourage or discourage various responses.

The use or non-use of certain words, and the negative or positive phrasing of questions, may make a difference. The investigator's manner should ideally be friendly, calm, neutral and non-judgmental. Surprise, puzzlement, approval, or disapproval, are all part of everyday communication and it takes conscious effort to avoid them.

Need for validity checks and controls. There have been few studies so far where attempts have been made to check the validity of the methods and conclusions. In part, this is because of the complex and subjective nature of the investigations and the additional effort and difficulties involved in testing for validity.

I will not discuss here the various possible ways one could introduce controls or test for validity or reliability. Some of these would be fairly straightforward in principle, such as using different procedures, more than one interviewer, different problems, different questions, different environments, analysis by others with different approaches, etc. However, I would like to mention one point, namely that any resulting conclusion, model, or theory of what is going on can only be considered useful or adequate if it enables one to make valid predictions about behavior and responses in other situations within the domain. That is, the model should be testable, and it should be falsifiable by contrary evidence. For example, if a student is categorized as "Aristotelian" in his or her understanding of motion, this has implications which can readily be tested.

CONCLUSION

The factors and difficulties discussed in this paper complicate cognitive studies of the nature of students' conceptions, and suggest care in the design of investigation procedures, and caution in the interpretation of response data. There is a need for precautions and controls, and tests for validity. Awareness and acknowledgement of the difficulties and potential pitfalls is important.

As regards research methods, the use of detailed clinical interviews or tutorial situations seems necessary so that the following can be adequately achieved: clarification and further probing of responses; following of chains of reasoning; distinguishing of immediate responses "off the top of the head" from responses involving reflection, and from responses involving the application of taught knowledge; judging whether ideas are vague, ill-formed and fragmentary, or clear and well-developed; revealing of any alternative co-existing ideas; judging the consistency of the conceptions; judging (and asking) whether a conception is held confidently or tentatively; judging whether the student holds a conception tenaciously or is fairly readily willing to modify it on the basis of further reflection or conflicting evidence; probing also the possible sources of the ideas (e.g. daily experience, or a school course), as well as the type(s) of thinking and knowledge employed (e.g. intuitive, analytic, analogical, etc.); evaluating whether extraneous factors (e.g. psychological, social) are influencing behavior and responses, and interpreting accordingly.

If students' ideas are studied in the individual tutorial/teaching situation, there are certain advantages in that the investigator/instructor can get to know and understand the individual student's thinking over a period of time and over many different situations, and can also learn to judge the extraneous factors. Minstrell[9] has done interesting work on mechanics in the teaching environmenta. Of course, learning, teaching, and conceptual charge are an integral part of the tutorial situation, which might seem to make an 'academic' study of conceptions more problematical. On the other hand, from an holistic research point of view, the study is conducted in a natural setting and context, and the findings could be more realistic and directly useful in the specific teaching situation.

As regards instruction, another point is commonly made about misconceptions, namely that they are often "highly resistant to instruction." The type of instruction is not always specified. If we presume that conventional group instructional methods, involving the presentation of the correct information, are usually involved, then it is not entirely surprising that formal instruction does not easily eliminate misconceptions. On the other hand, observation of individual students in demonstration interview situations (where no instruction is actually intended) shows that they are often remarkable ready to modify their ideas when they observe contrary evidence or reflect on inconsistencies, as they try to make sense of the situation. The unfortunate prevalence of misconceptions may be a by-product of the less satisfactory aspects of institutionalized educational approaches.

It is also noteworthy that the types of questions and situations used in probing misconceptions are usually different from the conventional quantitative numerical problems prevalent in conventional physics courses and end-of-chapter textbook exercises. The consistent and explicit inclusion of more qualitative conceptual questions[10, 11] in physics courses and examinations might redress an imbalance and help foster better conceptual understanding.

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NATURAL TENDENCIES IN ANALYSING STUDENTS'REASONING
TWO INSTANCES IN MECHANICS

L.Viennot

INTRODUCTION

In recent years a strong emphasis has been put on students'preconceptions.It is now widely accepted that underestimating the influence of preconceptions in knowledge leads to ineffectiveness in teaching. Indeed many researchers (1 to 16,among others) have shown that students'preconceptions may be highly resistant to instruction. When these preconceptions are organized in frameworks,they are all the more resistent to change. Moreover, remarkable similarities can be found between these alternative frameworks of reasoning and historical difficulties encountered in the evolution of physical theories. This is the case in mechanics. This gives still stronger evidence to the idea that students' mistakes are not simply outcomes of ignorance.

So it seems essential to take into account these preconceptions, prior knowledge or spontaneous reasoning, whatever the designation may be, in our teaching. There is a wide agreement (for instance 1 to 16) about strategies that would lead students to make explicit their own conceptions, to compare these to the accepted theory, to check their consequences on empirical observations and to evaluate their degree of internal consistency.

This being said, the best conditions for achieving success in such activities are not obvious. Partial failures in such attempts may be linked in particular to difficulties in interpreting students' responses in terms of"preconceptions" or "spontaneous reasonings". This paper discusses some of these difficulties and gives some examples of ensuing obstacles in interactive teaching strategies. We concentrate on two instances, chosen in mechanics because in this field many findings about students' reasoning are already available.

I QUESTIONS ABOUT PRECONCEPTIONS

The starting point of most studies about preconceptions is to point out some surprising responses or comments shared by a non-negligible number of children or students. Usually what surprises the investigator is that the response or comment is not compatible with the accepted theory, and this is all the more disturbing when the authors of such answers have "learned", in principle, this theory. This fact does not necessarily imply any value judgment or normative attitude: it is just that it is often easier to evaluate the part of previous instruction in wrong answers than in correct ones.

The next step is to find several questions having something in common which give rise to "surprising" responses which also have a common aspect. Then it is usually concluded that a preconception has been isolated. For instance, several studies already quoted (17) have shown that students in secondary school or at university often answer as if there was a direct relation, more or less linear, between Velocity and Force rather than between Acceleration and Force, or, to put it into more qualitative a form,as if "Motion implied Force"(Clement,1).We will refer to this kind of reasoning and to the related responses as "V-F" reasoning or "V-F" responses. In this field, the interpretation is based both on the consistency of some mistakes with the assumed preconception and/or on explicit comments such as " if the velocities are different, then the forces are different", or "zero velocity implies zero force", "there is an upward force that keeps the ball moving up" and so on.

A very natural question now arises as to what is the "source" of such a conception. This question, ambiguous as it is, is not easy to handle. We prefer to ask about which frame the conception at stake is inserted in, that is:

- what kinds of problems prompt the students to manifest this preconception?
- which formulations indicate its occurence in students' reasoning?
- which other features of spontaneous reasoning are linked to this conception, and in what way?

These questions, on which we comment in the next section, lead us to a more complex view of what a preconception is. But to ignore this complexity might cause us to miss out in discussing with students, as we show in the two examples discussed later.

II NATURAL TENDENCIES IN INTERPRETING STUDENTS' MISTAKES

There is a general tendency to forget that students' spontaneous reasoning is not necessarily expressed in the same terms as that of physicists. For instance when we say: "There is a kind of linear relationship between Velocity and Force instead of between Acceleration and Force", we seem to be still in a familiar landscape of well known concepts only connected by a wrong relation. But in fact there is no one-to-one correspondence between a concept of the theory and the assumed "notion" which allows a simple and synthetic description of students'spontaneous reasoning(2,10,20).

First, the range of problems which prompt students to use their "notion" of force in a "V-F" way does not cover the same domain as problems implying motions and/or forces in classical mechanics. In that sense, problem-solving strategies and preconceptions cannot be, especially in physics, considered as quite separate fields of research.

Moreover, a concept such as "force acting on a body" is well defined in Physics, always designated explicitly by the same word. On the contrary in spontaneous reasoning students are usually not concious of the "notion " they use and may call it, sometimes indifferently, "force", "impetus","energy", "momentum" and so on..

This lack of one-to-one correspondence between the two kinds of knowledge is connected with the fact that a spontaneous "notion" may appear as made of a mixture of ingredients seemingly borrowed from different concepts of Physics. There are links to be explored that bridge several chapters of our physics textbooks, sometimes in unexpected ways. In that respect, we must handle with care our famous "everything happens as if ...". A very natural attitude indeed is to interpret students' mistakes with a kind of "minimum hypothesis": the student is assumed to have in mind some additional data or statement, or to have misunderstood the question in a way that would give a simple account for his or her answer in the frame of the accepted theory. For the sake of simplicity, one makes interpretations that put into play as few concepts as possible, thus avoiding the"conceptual mixtures" evoked above.

For instance, if the existence of friction seems to account for a student's comment, it is tempting to take this interpretation for granted. Or a centrifugal force wrongly drawn on a force diagram is likely to be interpreted as if the student had in mind another frame of reference than the one proposed in the text. An ambiguous response frequently leads teachers to complain about an inadequate wording, as if it was only a matter of wording..

In the author's experience, these tendencies are very common among physicists. Reading research reports sometimes leads to the same conclusion. Let us see now more precisely which limitations may occur when these tendencies are prevailing.

III FIRST EXAMPLE: "STUDENTS ARE ARISTOTELIAN"

This comment is very common among teachers and researchers aware of the "V-F" preconception. Indeed a relationship between force and velocity immediately reminds one of Aristotle. Such a comment may be harmless if its meaning is well specified as equivalent to another one, for instance "the objects move in the direction you push them" (6). But it may also suggest an interpretation regarding the "source" of such a reasoning and consequently focus instructional interventions on too exclusive an aspect:

A further link is often assumed between an Aristotelian reasoning and the existence of friction in real world. In case of friction indeed, and for a given constant additional force acting on a body, the velocity sooner or later reaches a limit value proportional to the additional force, as shown by every day experience. Such an hypothesis, simple and logically consistent with the "V-F" reasoning, may lead when accepted to teaching strategies that emphasize motions with or without friction, experiments on air tables and so on..

A closer analysis of the results obtained in the studies quoted above throws some doubt on this very simple and physics-like interpretation. Let us go over the questions listed in section I

a) Which kind of questions gives rise to these "V-F" reasonings?

Several studies (1,10,11) seem to indicate that all problems are not equally likely to provoke "V-F" responses. Questions presented in a very formal way do not often lead to such answers . This kind of reasoning occurs mainly when motion is a striking feature of the proposed physical situation, i.e. when it is given in the text in a figurative way - drawing, verbal description - and not in an analytic form (10,11). Moreover, every motion is not equally propitious to "V-F" responses. These appear more frequently when no well-known force of interaction can "explain" the motion, i.e. is in the same direction as the velocity, or when a force is missing to "explain" a zero velocity which, in the "V-F" reasoning, goes with a zero total force. In such cases, forces are invented to fit in the "V-F" needs.

The most simple example is a ball thrown up in the air: "V-F" responses are more frequent and more persistent when students cope with the first part of the motion, where the ball keeps going up then "stops" despite its weight, than with the second part of the free fall, where the ball moves and steadily accelerates under the action of gravity (1,10,11).

Some results of the now classical pendulum test remarkably illustrate this point(11).

A version of the pendulum test:

> A point mass m freely oscillates (diagram 1,2,3) or turns (diagram 4) in a vertical plane, at the end of a tight string whose length is l, whose mass is negligible, and whose other end is fixed at point C. Frictions are neglected. In each case below, trajectory (dotted line), velocity V, and angular position of mass m are sketched.
>
> On each diagram, draw the total force F acting on mass m as well as its normal (F_N) and tangential (F_T) components. Explain your answers.

The diagrams are drawn in Fig. 1 (col.1). Right total force (Col.2) and common mistakes (Col.3) are also shown. This test was given to 60 students in their first year in a scientific curriculum at university in Paris, after a two months introductory mechanics course.

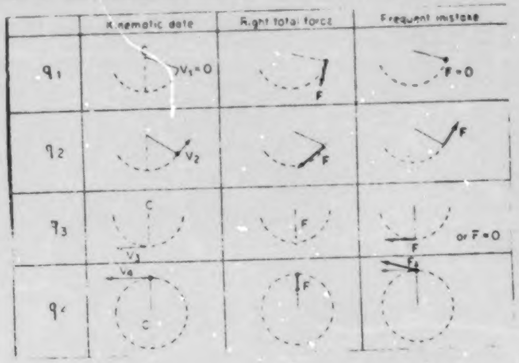

Fig. 1 :
Main features of the pendulum test

Part of the results are given in Table 1

Col. 1: rate of answers bringing in "invented forces" fitting in the "V-F" reasoning, in a drawing or in a comment which may sometimes contradict the force diagram: "but in fact the total force is null (q1)", or "Why would the pendulum go up if the force is null ? (q3)".

Col. 2: Rate of force diagrams showing up real interaction forces, i.e., weight of the mass and tension of the string

Col. 3: Rate of force diagrams where the tension of the string (thus labelled by students) is represented in a direction opposite to the correct one, i.e. is centrifugal.

Col.4: Rate of force diagrams showing up a centrifugal force (thus labelled by students or with no label at all).

N = 60	"V - F" responses	real interaction forces	reversed tension	Centrifugal force
q_1	12 %	78 %	0 %	0 %
q_2	26 %	70 %	0 %	10 %
q_3	31 %	58 %	0 %	2 %
q_4	37 %	25 %	12 %	18 %

Table 1: Some results of the pendulum test

A very striking feature in Tab.1 is the following: the proposed situations prompt a diminishing percentage of answers to q1, q3, q2, q4 that recognize and accept real interaction forces P and T. In the same order, they provoke more and more responses in terms of "V-F" type invented forces. In other words ,the less satisfavtory real forces seem to be to explain the motion (q4),the more frequently they are denied and replaced, or completed, by invented forces.

These findings show that some reservations must be put on the statement: "students are Aristotelian". Were they so, they would restrict their Aristotelian reasoning to a limited set of situations that could not be predicted only from the existence or absence of friction. When presented with other situations, for instance the downward phase of a free fall, they are more likely to keep to the interaction forces only, and to accept and use the Newtonian relationship between force and acceleration, in spite of the existence of friction in these situations.

b) Which formulations indicate "V-F" reasoning?

Going over students' comments about the situations evoked above, free fall of a ball or pendulum, it is worth noting that the subjects do not often say "force acting on...(the ball, the mass) ", but more likely "the force of the throw", "the upward force you have given it ", "the mass has a force", "the upward force of the mass" (1,7,10,16). This kind of comment is specific of "V-F" reasoning, and it is not at all Aristotelian, as in Aristotle's view the cause for the "violent" upward motion of a thrown object had to be searched outside the object: thus the complicated story of air motions around the projectile.

In the spontaneous reasoning we are observing, the "cause" of the motion has to be searched first in the past of the motion -"the force of the throw"- , then considered as subsequently stored in the moving body - "the upward force of the mass" -. This stored quantity, elsewhere called "supply of force" (10), appears to be not clearly a force and to have a strong energetic component. It may indeed be designated in students' comments by a variety of words including "force" and"energy" as mentioned above. This fact should not be interpreted as a mere verbal substitution nor limited to a matter of designation. Rather, it leads us to confront with our third question.

c) Which other features of spontaneous reasoning are related to this conception and in what way?

A previous study (10-11) shows that the very structure of students' responses in problems presented in energetic terms may be typical of "V-F" reasoning, regardless of which words or algebraic expressions are used by the subjects inside the dynamic/energetic vocabulary.Thus students in first year at university, when presented with this problem:

" A mass is at rest on top of a spring. How far has the mass to be pushed down so as to rise off the spring when it is released ?"

comment as follows:

" The force of the spring	must overcome	the weight of the mass "
" $\frac{1}{2} k (z-l_0)^2$	>	$mg (z - l_0)$ "
" $\frac{1}{2} k (z-l_0)^2$	>	mg "
" $k (l_0 - z)$	>	mg "
" Reaction of the spring	>	Action of the mass "

This kind of force-energy mixing has been shown in the same study to be linked with questions which prompt "V-F" type reasoning. On other occasions the same students are able to handle correctly homogeneous expressions. The same specificity is observed (10,11) for another aspect of "V-F" type reasoning, not developped here for sake of brevity. That is a global way of regarding a motion in which forces are not necessarily attached to specified positions of the projectile, nor linked to instantaneous accelerations, but rather to the preceding phase of the motion seen as a whole (18).

These aspects of students' reasoning - selective intervention of the "V-F" reasoning according to the type of problem (i.e. relationship preferably oriented in the V ⟶ F direction), dynamical terms being ascribed to the object itself in a rather animistic way, force energy mixing , global analysis of motion - are essential points to know. These might be lost by too reductive a formulation such as " students are Aristotelian " or "they mistake velocity for force".

If we were to compare the spontaneous reasoning of our students with something, we would rather choose the pre-Galilean theories of "Impetus" (11) as Clement (1) and Mc Closkey and al. (13) also remarked. The main features of "Impetus", for example the ability to be stored - "impressed" - in objects of greater or lesser "impetussic capacity", as well as the fact that it is gradually used up in an upward motion, or that it may explain to a certain extent the famous relativistic problem of a stone released from the mast of a ship, are strikingly similar to the attributes of the "supply of force" that seems to underlie our students'responses.

Coming back to our first concern, i.e. interactive teaching strategies, it seems that too simple an idea of our students' views may result in missing some essential aspects of students' difficulties. Here these difficulties appear to be linked not only with friction, but also with the very concept of force acting on something, at a given time, and with the distinction between force and energy.

In particular one should be aware, in teaching as well as in research investigations, that one may tap quite different reasonings when speaking of "force on something", of "force of .. something", or of " a force" not further specified.

Ensuing links between "V-F" responses and common mistakes about Newton's third law for instance (10,11) also seem important to keep in mind when discussing with students. The next example provides an opportunity to emphasize the existence of such unexpected connections between different aspects of Physics.

IV SECOND EXAMPLE: THE CENTRIFUGAL FORCE

Consider now the common mistake which consists in adding a centrifugal force on a force diagram for a body in circular motion in a Galilean frame (Fig.2).

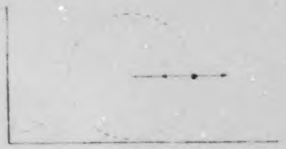

Fig.2: common mistake in the force diagram for a stone in circular motion in a Galilean frame

The interpretation which is the most natural for a physicist is in terms of frames of references. The physicist concludes either that the student has changed frame of reference without warning, or if he or she has read about preconceptions in this field (9), he or she concludes that the student was not even aware of the existence of frames of reference. A logical conclusion would then be to put a strong emphasis on this matter in teaching.

Again such an interpretation, limited as it is to a definite chapter of Physics is incomplete and may lead to partly ineffective teaching strategies. Indeed, there are several indications that centrifugal force is not just an inertial force transposed from one frame to another, or at least that it is not always the case.

First, the results of the pendulum test (Tab.1,Col.4) show that a centrifugal force does not enter into students' reasoning with the same frequency for every case of circular motion. The maximum rate of occurence of "centrifugal forces" is reached in question 4, which is also the only case where the tension of the string appears to be "reversed". These findings suggest that centrifugal force and reversed tension might fulfil the same function, namely to balance out the interaction forces -which are downwards in question 4 - thus explaining why the mass "does not fall". Indeed spontaneous reasoning requires that there be a zero force along the string, because there is no radial velocity. In the other cases, the radial component of the weight is available to fulfil this role, so that there is no need for any centrifugal force (q1, q2, q3). In that respect it is worth noting that even some experts, when they lack time to reflect, wrongly say that in question 2,3,4 (and not only in question1) the radial component of the weight balances out the tension of the string.

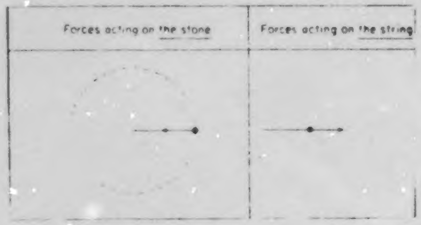

Fig.3: Correct force diagram for the circular motion of a stone in a Galilean frame

Second, there is a centrifugal force when a stone moves in a circular motion in a Galilean frame, but it is acting on the string (Fig.3). This is a direct outcome of Newton's third law.So the point here might be that students do not shift from one frame of reference to another one, but from one object on which the force is supposed to act to another one. We are thus led back to the question of what a force is acting on. Ambiguousness on this point is strongly reinforced by the spontaneous tendency, stressed above, to ascribe forces to objects, which allows the following drift:

Centrifugal force: Force acting on the string exerted by the stone

↓

Force of the stone on the string

↓

Force of the stone

↓

Force on the stone

It would seem that discussions with students on this point should not be limited to the notion of frames of reference, but should bring in other features of the "spontaneous centrifugal force" : stored quantity due to the phase of circular motion preceding the time considered, balancing role, ambiguousness about what the force is acting on

CONCLUSION

This brief discussion offers two examples of the kinds of risks we take when making too straightforward an interpretation of our students' mistakes or ambiguous answers. Numerous examples can be found in other fields (see for instance 9).

The subject of ambiguousness would deserve a whole development in itself, as it is sometimes one of the most significant aspects of students' reasoning. Yet physicists often qualify ambiguous answers as improper to be analysed because improper to be evaluated.

This being said, we physicists are justified in starting with such a minimum hypothesis as "they have just changed frame of reference", first because it is the simplest thing to do and second because it often works, at least partly. But it is important not to stop here and to check a first interpretation on as many types of problems as possible : another way of describing students' responses, carrying fewer physics-like reasonings, may then turn out to be more effective to guide our interactive teaching strategies.

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Misconceptions Misconceived? Using Conceptual Change to Understand Some of the Problems Pupils Have in Learning Science

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Introduction

After a rather lengthy discussion aimed at initiating pupils into some of the novelties of biological classification, the following discussion between teacher and pupils takes place.

Teacher: Now, let's divide all the living things into two divisions. Into what two divisions can we divide every living thing?
Every living thing is either a _____ or a _____?
Susan, give me one division.

Susan: People?

Teacher: People are just part of one of the two divisions.

Sid: Plants and animals.

Teacher: Good for you Sid. That's right. Every living thing in this world is either plant or animal. People, Susan, are animals so they fit in this division.

Susan: People aren't animals, they're humans.

Teacher: People are animals, the same as dogs and cats and so on. (Much laughter and several loud objections by a large number of pupils speaking simultaneously. It appears that pupils disagree with this last statement.) People are animals! What's wrong with that? They're not plants are they?

Peter: But people talk, and have two legs and arms, and move and can think. Animals aren't like that. (Laughter)

Teacher: People do think, and this makes them one of the highest forms of animals, but they are still animals ... and other animals communicate with one another ... (Several pupils are noisy and visibly disturbed.) ... That's enough ... People are animals. Now maybe it would help if we looked at the differences between plants and animals. What are the differences? There are at least three that you could name.

Danny: Animals can walk plants can't. ...

The episode captured in this transcription, it seems reasonable to assume, typifies something that occurs not infrequently in a wide range of science classrooms. Interestingly, however, it is not until fairly recently that goings on such as this would have occasioned any more than a cursory glance from researchers in science education. Nevertheless, in the past ten or so years, all of this has changed quite dramatically. Certain aspects of this exchange between teacher and students exemplify the sort of thing that has become a matter of intense interest and widespread research among members of the science education community; especially among those who, in various ways and for a variety of reasons, are concerned to gain more insight into pupils' understanding of science. Research efforts, many of which were diffuse and piecemeal, were given a "shot in the arm" by Easley and Driver's fine review (1978), which helped to put the field in a new light.

What is it about what's taking place in this encounter that would be of interest to researchers of the sort whose work is surveyed by Easley and Driver? In the most general terms, we might say that it's the fact that something unexpected has happened, or that something has misfired or gone wrong. And of at least equal importance is the fact that the source of the difficulty centres around two rather fundamental biological concepts; those of an animal and a human. These two facts combined with the assumption that "the problem" lies with the pupil, has led quite naturally to talk of pupils' preconceptions, misconceptions or mistakes. Accordingly, pupils are credited with holding a substandard belief, or having engaged in a substandard performance. In short, the presumption is that the pupils are in error or have made an error.

In the context of a tendency in the direction of this sort of talk, I would like to enter a strong plea for tolerance and a better understanding of students, and against hasty classifications and well-intentioned but ill-conceived attempts at solutions. There's more to error than meets the eye. Indeed, it has been suggested that Spinoza "was so metaphysically embarrassed by [the notion of error], that he denied its existence, saying that what appears as erroneous reasoning is instead the correct solving of a different problem" (Boden, 1981). Recent talk of misconceptions in the literature of mathematics and science education carries with it the suggestion that something has been botched or bungled, or that something has gone amiss, awry, or in some other way fallen short of the mark. But once superficial assessments have been set aside and replaced by more insightful and penetrating analyses of the kind now appearing in the field, one comes to have some sympathy for Spinoza's position. Even if one is prepared to acknowledge that people are capable of error and that something has misfired in a particular episode, it often remains unclear what sort of error one is dealing with and to whom it should be charged. In our opening passage, for example, have the students (e.g., Susan and Peter), got the wrong idea about animals (i.e., that humans are not animals)? Or, by contrast, does the teacher have inappropriate expectations in respect of her pupils, i.e., that there is one acceptable concept of an animal and that it is the one currently endorsed by biologists? Or, again, is the teacher confusing matters by insisting that 'people' is a biological term. In this instance, just as in many others one encounters in the literature, it's difficult to determine whether what we're confronted with is a genuine, full-blooded, misconception or whether, by contrast, we've encountered a misinterpretation (i.e., what social psychologists refer to as an error of attribution) of the performance or of the views underlying it.

In what follows I want to explore how some of the recent work in the history and philosophy of science may be used to give us a more adequate understanding of students and the nature of some of the important intellectual problems they confront in their early encounters with formal instruction in science. Accordingly, in part I of the paper, I sketch three main theses concerning the development and role of theories in the sciences which seem to have won general acceptance within the philosophy of science. Part II attempts to lay some of the groundwork for the contention that there is an important analogy between scientific theories and students' frameworks, by suggesting that their "untutored" performances in classrooms and elsewhere, can quite properly have been seen as reflections of theory--namely, commonsense theory or theories. This then puts us in a position to view some of the barriers or roadblocks turned up in the research on misconceptions as due to tensions between commonsense and scientific theory, which are similar to conflicts between theories within a science. Against this background, part III is taken up with a further discussion of the merits of commonsense-scientific theory analogy, the primary point of which is to underline the need for caution in our talk about misconceptions, and so on, until we know a great deal more than we do at present about the nature and role of commonsense theory. The concluding section, part IV, offers some suggestions for further research meant to help provide us with a better understanding of students of science.

I. Contemporary Philosophy of Science and Conceptual Change

I want to consider three main assumptions which, in spite of important differences in the views with which they have been associated, seem to have engendered considerable consensus in recent work in the philosophy of science and in the theory of perception. My aim is ultimately to suggest ways in which they might help to throw light on the form of understanding students bring to formal science instruction, the kind of understanding that marks a sophisticated grasp of science which education may seek to foster, and the relation(s) between them. What I have to say here is merely suggestive and freely adapted from Suppe's (1974) very useful summary.

A. The Theory Dependency of Observation

The first assumption is that "observation is theory-laden" (p. 191). Put somewhat differently, this is the thesis that perception is influenced by the concepts, beliefs, expectations and prior knowledge of the observer. Hence, confronted with the same phenomena (or sensory inputs) adherents of different theories will observe different things. Hanson (1958) illustrates this point by inviting us to imagine Kepler and Brahe encountering the dawn. Would they both see the same thing? Or would each see something different? Based on the view described here, Hanson suggests that Tycho would see the sun as rising, whereas Kepler would see the earth as moving away from the sun. Under what circumstances, might they come to see the same thing? As a minimum, it would require that they come to share some of the relevant concepts, beliefs or theory. This is the thesis of the theory-ladeness of observation.

B. The Meaning of Scientific Terms Depend on Theory

The second assumption is what might be called the thesis of conceptual change or meaning change. Suppe outlines it this way.

> Meanings are theory dependent: The descriptive terms (both observational and theoretical) used by a science undergo a shift in meaning when incorporated into, or used in conjunction with, a theory; thus the principles of a theory help to determine the meanings of the terms occurring in them, and so the meanings of such terms will vary from theory to theory; hence changes in theory result in changes of meaning. (p. 191)

A helpful illustration of this thesis is afforded by considering the change in the meaning of the term 'planet' as it occurs in the geocentric view and later in the heliocentric view.

In the former, 'planet' means body traveling around the earth. But in the later, it means body traveling around the sun. The same term, in other words, has a very different meaning in the context of the two theories. Moreover, the class of objects to which 'planet' refers differs in each case. On the geocentric account, the sun is a planet; on the heliocentric view, it is not.

C. Standards for Assessing the Adequacy of Scientific Theory

The final assumption has to do with standards of assessment. Negatively put, it's the thesis that observation or "the facts" alone cannot be used to judge the adequacy of competing theories, since there are no neutral facts on which to base the judgement. In a more positive vein, this notion may be expressed as the claim that the relative merits of rival theories must be assessed by appeal to other criteria governing the purposes and practices of the scientific community. For example, the view here is that, at the time, observation alone was not enough to tip the scales in facour of Kepler over Tycho.

Now just what these standards are and how they are employed in the assessment of scientific theories represent extremely controversial issues (c.f. Suppe, pp. 208-221, for extended discussion). Coherence, comprehensiveness, explanatory power, theoretical fruitfulness, and so on, have all been advanced as criteria of rational choice between competing theories.

This rough and ready sketch provides an account of some of the workings of science which stands in sharp contrast to a variety of earlier views connected with logical positivism, certain forms of empiricism and so on. Nevertheless, more important for present purposes is the fresh perspective it affords on such things as the role of language, concepts and theories in observation. In particular, on what might be at work when adherents of different theories report different observations while observing the same phenomena, how different scientists using the same term may mean quite different things by it--depending on the theory to which they subscribe, and on how at least some of the central terms, or concepts, current in a science may undergo fundamental change when the theory within which they are embedded undergoes significant transformation. And, finally it alerts us to the fact that the choice between different and perhaps rival theories is no simple matter to be settled merely by appeal to "the facts of the case", as it were. Other considerations, associated with the standards and purposes of the scientific community, must be taken into account if the choice is to be a rational one.

All of this may provide some insight into the dynamics of science; but how does it throw light on the seemingly peculiar views entertained by the likes of Susan and her friends that are the focus of this seminar, on how we might learn more about them, and their possible bearing on our efforts to initiate pupils into science?

II. Commonsense, Students' Views and Theory

A. Students' Views and Commonsense

What's required is a much better appreciation of the sources of these views in the concepts, beliefs, and understanding students bring with them to formal instruction in science. To begin with, it seems evident that children come to school already equipped with a more or less sophisticated understanding of how the world works: they have some understanding of what to expect from the medium sized dry goods of the world, of how to get on with others, of how to satisfy their desires, and so on. This stock of understandings gradually picked up from earliest childhood may be referred to as "commonsense" or "commonsense understanding". Commonsense, then, is the range of concepts, beliefs and values that people share which provide a basic view of the world, of their position in the world and of how they ought to act. The existence of a commonsense scheme is crucial, for on it depends the very possibility of communication and other forms of social relations.

B. Commonsense as Theory

Our primary concern here is with the view(s) of the world contained within commonsense frameworks. In this connection, I will adopt the view, argued for vigorously and imaginatively by Churchland (1979), that the commonsense framework is a theory, or a series of more or less loosely connected theories. Churchland puts the matter in this way, "If viewed warily, the network of principles and assumptions constituitive of our commonsense conceptual framework can be seen to be as speculative and as artificial as any overtly theoretical system" (p. 2).

From whence does the theoretical framework(s) of commonsense spring? On this view, their roots are to be found

> not in the nature of the perceptual environment, nor in the innate features of our psychology, but rather in the structure and content of our common language, and in the process by which each child acquires the normal use of that language. By this process each of us grows into conformity with the current conceptual template. (Ibid.)

The present scheme of concepts is simply the latest phase in a long evolutionary process that has given rise to it.

Of special interest to participants in this seminar, especially those who have been exploring children's notions of heat, is Churchland's account of some of the key features of our current commonsense conception of heat (p. 23).

C. Student Performances as Embodying Commonsense Theory (or Theories)

In order to understand the things pupils say and do in classrooms, clinical interviews, and so on, I think we must assume that their performances and the views they espouse are a significant reflection of the commonsense theory (or theories). In the absence of some such assumption, it's hard to see how one could find their actions intelligible. There must be some shared basis for assigning meaning to their words and deeds, otherwise communication with them would be impossible. In other words, talk about preconceptions, misconceptions, alternative frameworks and the rest, makes sense only against the background of shared understanding or common ground. The most plausible candidate for this common ground is the commonsense framework.

III. Commonsense, Conceptual Change and Understanding Students

In this section, I want to briefly explore some of the consequences of adopting this perspective for gaining further insight into the findings turned up by research on pupils' misconceptions or alternative frameworks as they pertain to science education. In particular, I would like to consider what light can be shed on the sorts of difficulties revealed in literature by assuming that pupils' performances in classrooms, clinical interviews, on questionnaires and so on, are a significant reflection of the commonsense theory: a theory or set of theories which are similar in important respects to fullblooded, mature theories in science.

A. The Theory Dependency of Meaning

Let us begin by first considering the second of the three assumptions taken from current philosophy of science, i.e., that meanings are theory dependent, and that changes in theory result in changes of meaning. This helps to explain why a vast majority of the terms receiving the most attention in this research, e.g., 'mass', 'volume', 'density', 'motion', 'force', 'work', 'light', 'heat', 'living/non-living', 'animal/non-animal', and so on, lead a double life. That is, not only do they have a relatively well fixed scientific meaning, but they also have one or more often strikingly different, and equally fundamental, uses in everyday commonsense discourse. 'Fruit', provides another delicious example. Unless the appropriate context is supplied, even a sophisticated adult can be tripped up by a question like: 'Are peas, potatoes, tomatoes and nuts all fruits?' The second assumption, namely that meanings are theory dependent, helps to explain why: The point is that 'fruit' has a very different meaning (or meanings) in the commonsense theory than it does when it is used for purposes of biological classification. So, while it's not unreasonable to assume that the scientific use of 'fruit' may have grown out of ordinary usage, the culinary sense of fruit owes its significance to a theory bearing no immediate or obvious logical connection to its biological counterpart. Thus, in order to understand the meaning of the term, one must have some grasp of the relevant theory.

Returning to the incident transcribed at the outset of the paper, it's fascinating to consider what might be going on here. Clearly some sort of misunderstanding has developed. But what are we to make of it? A variety of explanations might be advanced; that the problem is merely definitional, that the pupils have the wrong idea (i.e., a misconception) about animals, that the pupils have failed to generalize (Bell, 1981), and so on. On the assumption that meanings are theory-dependent, let me propose another alternative--admitting the evidence is thin; namely that, what has arisen here is a case of miscommunication or cross purposes. The teacher is putting forward a bit of good old fashioned Darwinian taxonomy. This is her theory and the source from whence the meaning of 'animal' and with it, of 'human being' (or better homo-sapien) derives. What about Susan, Peter and their rather vociferous colleagues? They, I venture to suggest, are up to something quite different. With Peter as their most articulate spokesperson, they appear to have some grasp of, and seem to be advancing, a theory of persons, according to which 'person' and 'animal' are fundamentally different categories. [The latter in an embryonic form bears at least some superficial resemblances to a view suggested by Descartes, and another outlined more recently by the philosopher, P.F. Strawson, 1959).] In attempting to rebutt the teacher's assertion that "People are animals, the same as dogs and cats and so on", by countering, "But people talk, and have two legs and arms, and move and can think. Animals aren't like that." Peter seemingly relies on one of two commonsense concepts of an animal; i.e., animal as "a lower animal distinguished from man" (Merriam-Webster, 1974), or as "a four legged terrestrial mammal" (Bell, 1981). In short, teacher and pupils seem to be invoking two radically different concepts of an animal deriving from criteria sssociated with quite different theories. Thus, although the participants in this discussion make use of the same terms, they mean quite different things by them. (Indeed, we might describe this presumption, viz., that people using the same term mean the same thing by it, as the fallacy of transparent meaning.) In a system of classification based on some version of the theory of evolution, talk about people as persons makes no sense, i.e., has no literal meaning, simply because these terms, or their associated concepts do not figure in that theory. On the other hand, in the light of the theory Susan and Peter seem to be espousing, talk of people as animals is, likewise, unintelligible. And, it is likely destined to remain so until they begin to catch on to the theory in the context of which such claims do begin to make sense (or to make quite different sense). Until then, what they learn is unlikely to make clear sense to them, although they may demonstrate considerable proficiency at the purely verbal level. In any event, until such time as there is some recognition that animal is being used very differently by teacher and students, their claims and counter claims will pass one another by.

The parallel between the geocentric and heliocentric uses of planet, and the commonsense and technical uses of 'animal' (or 'heat' or 'mass' or 'force'), in the light of the view that meaning demands or theory is instructive in another way. For it suggests that the incorporation of terms at home in the commonsense framework into a scientific theory may well give rise to a significant change in their meanings. And in virtue of such change there may emerge a gap between the ordinary and technical uses of these terms. Nevertheless, given that science grows out of commonsense, it also suggests that it might be extremely useful for us to examine the relations between science and commonsense with a view to identifying similarities which may enable us to bridge some of these gaps.

What might be done to help these students to move from commonsense to biological classification? The answer is unclear for at least two reasons. First, because we need to know a good deal more about the current commonsense view of persons, animals, and so on, how it came to be as it is, and how it may be similar to, or differ from, the biological notions of homo-sapiens and animals. And, secondly, given the fragmentary nature of the information afforded by this episode, it is difficult to determine just what version of the commonsense theory these pupils are entertaining. What, for example, do they have in mind in saying that people talk or have two legs? What I am suggesting here, in other words, is that, unless and until we know what theory they are espousing, we are simply in no position to say that the assertion that people are not animals represents a misconception! On the other hand, it would seem profitable to explore what has gone on here as if it reflected a gap or a tension between theories.

B. The Theory Dependency of Observation

Let us now consider how the first assumption, i.e., that observation is theory-laden, can throw light on our efforts to learn more about what is involved in pupils' efforts to understand scientific conceptions or theories. Sometimes in research of this kind pupils are presented with a series of experiences ("observations"). On the basis of these encounters with phenomena they are commonly asked to do one of two things--without coaching. Either they are expected to abstract from these experiences the relevant principles of scientific classification. Or they are requested to provide the appropriate scientific explanation of, or to make predictions concerning, the phenomena in question. For instance, pupils might be presented with a pea, a pear, a potatoe, a tomatoe and a nut, and asked to determine what they have in common, in the expectation that they will come to observe them as members of the class of fruits. Or they may be confronted with a piece of apparatus and either asked to forecast what will happen if it is manipulated in certain ways, or to explain what manipulations have led to its being in its present state. Now the notion that observation is theory-dependent, warns us that so long as they remain ignorant of the theory, there is no reason to expect pupils to attend to the fact that these items are associated with the seed bearing part of plants. Moreover, even in the case where they do happen to know the appropriate bit of theory, it is a mistake to think that, in the absence of further instruction, they must automatically observe these objects in biological terms; rather than, say, in geometric ones - e.g., as having a certain more or less rounded shape. To suppose that there is one unique way of observing and hence of classifying, describing and explaining phenomena, is to commit what R.F. Dearden (1968), has called "the fallacy of perfect obviousness". One commits this fallacy if one takes it for granted that "... what unavoidably presents itself to a theoretically sophisticated observer is there for all to see." (p. 118).

Now there would be no harm in this were it not for the fact that a primary purpose of this research is to determine what pupils actually do know or understand. Unfortunately, in circumstances such as those described here, the pupils' performance is often judged to be substandard. As a result they are credited with some sort of deficit or with having made an error. Yet, if what has been suggested here is on the right track, there is indeed a problem in what has taken place. However, the problem seems to reside not in the pupils' performance. Instead, it is to be found in the researcher's interpretation (misinterpretation) of it. And here, once again, Spinoza's worry comes to seem increasingly more credible. Accordingly, we see once again in these contexts that talk of misconceptions is misleading, or at best premature.

C. Standards for Assessing the Adequacy of Theory

The third and final assumption has to do with standards for judging the merits of scientific theory or for assessing the adequacy of competing scientific theories. The problem here is extremely complex and controversial (cf. Suppe, pp. 209-217). The general point around which there does seem to be consider-agreement is, nevertheless, instructive--especially for present purposes. It's the view that when theories compete with one another within science there is no way of deciding which is the more adequate merely by appeal to observation. For there are no neutral observations to which to appeal in determining which of the rivals is the more adequate. Accordingly, the judgement must be grounded on other features of the context in which the rivalry occurs. A variety of other virtues of theory have been mooted as criteria on which to base such a choice. These include coherence, comprehensiveness, explanatory power, potential fruitfulness, certain canons associated with methodology or research design, and so on.

Now against this background of this and the other assumptions sketched here, it becomes plausible to suggest that the apparent tensions between the scientific and commonsense notions of animal, heat, fruit, work, etc., and the frameworks within which they are embedded can profitably be explored as if they represented some sort of conflict or discontinuity between theories (cf., for example, Hawkins, 1978; Nussbaum and Novick, 1981; Posner, Strike, et.al., 1982). Nevertheless, if this perspective is to give us any genuine traction on the problems we've been considering, we must be extremely cautious about the assumption, implicit in some of this research, that these conceptual schemes or theories can rightly be compared and judged as if they were competing for the same ground *within* the domain of science. If we were to adopt this position, and treat commonsense theory, or pupil's versions of commonsense theory, as being on all fours with the relevant scientific theory, then we would immediately set out to identify anamolies, to collect counter-examples, to draw attention to phenomena not explained by commonsense theory, and so on. The sole point of the exercise would be to extol the virtues of the scientific framework, and impugn the integrity of the commonsense view. Given what was said earlier about science and about commonsense, to engage in such comparisons in the absence of a good deal more background information about students and their theories would be to commit the fallacy of common ground. It is the assumption that the merits scientific theory and commonsense theory can inevitably be evaluated by appeal to the same criteria.

Indeed, recent empirical research in this domain has increasingly begun to suggest that there is very little action on this front, as long as the name of the game is science. For example, Easley and Driver (1978) remark in respect of one of the early attempts in this direction that,

> It was apparent that the counter-examples, and conflicting evidence did not of itself encourage a change in the pupils' thinking, and at times produced only confusion. Where an alternate theory was presented either by the teacher or by other pupils, which better accounted for the data it was not necessarily understood, but was accepted and learned at a verbal level. (pp. 78-79).

Ausubel (1968), Hawkins (1978), and Viennot (1979) have commented on the tenacity of these views and their resistence to patient explanation or other forms of didactic instruction.

The problem is that if we persist in regarding science as the only, or the ultimate, court of appeal in situations of this kind and thereby treating commonsense as a naive or degenerate version of scientific theory, we are left with a series of highly implausible explanations for the tenacity of these views. Indeed, we might thereby deem it proper to dismiss such resistance to change as a kind of conceptual inertia, intellectual laziness, a lack of ability in science, stupidly, or, in extreme cases, appeal might be made to "arrested development" or even irrationality. The trouble with taking this tack is that it doesn't accord very well with other things we know. For example, in taking issue with the claim that people are animals, our grade five pupils seem to display none of these qualities. Moreover, it would leave us extremely hard pressed to make sense of Viennot's (1979) very telling observations that the intuitive (commonsense) scheme "reappears in the expert when he or she lacks time to reflect" and that "teachers make similar mistakes when they answer in a hurry." (Ibid, p. 213). To pursue this point a bit further, I would be very surprised indeed to learn that, once outside the laboratory or the classroom, experts and teachers did not conduct their lives under the guidance of the commonsense framework, whether they happen to be shopping for peas and potatoes as vegetables to be used in the main course of the meal or merely watching the sunrise. I strongly suspect under most conditions of ordinary living the return to the scientific view requires something akin to reflection or, perhaps, an act of will. Are we to say of these people that they at times labour under the same misconceptions that are so readily attributed to the uninitiated? After all, are we confident that the return to commonsense under certain circumstances and for purposes constitutes some sort of blunder, mistake, or ill-considered response? Or, is it better understood as an intelligent adaptation to the circumstances?

A more plausible approach would involve retaining the idea that there is some sort of impasse between commonsense and science--especially for the uninitiated, while changing the venue of the court of appeal so as to permit commonsense (or intuitive) schemes to receive a more detailed, open, and just hearing than they have gotten up until now. An important part of this new and more comprehensive assessment would be an examination of the merits of the competing views in respect of the contributions they make to peoples' capacity to get on with their lives. Perhaps the most significant consequence of this expanded focus, at least from the point of view of the research discussed at this seminar, is that we must begin to take the viewpoints of those we study more seriously. That is to say, we must come to see this seeming clash between theories, as a clash between theories competing for the sensibilities of persons for whom scientific truth, explanatory power and so on, are not the only, or even the most important, concern in their lives. There is a risk however. It's simply that the more we understand the more likely we are to come down on the side of Spinoza: Misconception, or Misinterpretation?

IV. Some Suggestions for Further Research

The focus of this paper has been on using some of the insights coming out of recent work in the philosophy of science as a way of understanding some of the problems students experience in learning science. These have been used to suggest that students often encounter an impasse or a tension between science and commonsense. Yet, to suggest that the difference between the two is radical would, I suspect, be to overdraw the contrast, especially given the further assumption that science has grown out of commonsense. On the other hand, we must also avoid the other extreme, which involves supposing that science represents a perfectly natural and transparent extension to, or refinement of, commonsense under the auspices of exactly the same canons of inquiry.

The view being put forward here, in other words, is to be taken as suggesting that commonsense theory (or theories), the conditions under which they change, the standards for assessing the merits of competing views, and so on, be treated as problematic. In other words, commonsense views can properly be regarded as legitimate objects of inquiry. At present, there is a good deal about the commonsense framework that we do not understand in any explicit and systematic fashion. Accordingly, until we have a much better picture commonsense theory (or theories) in general, the purposes they serve, etc., it seems wrong, or at least premature, to maintain that a given view constitutes a misconception simply because it parts company with the current scientific view.

Turning to research of the kind of interest to the majority of those participating in this seminar; here, too, much remains to be done. One of the principal priorities in this domain should involve setting out to develop richer and more detailed portrayals of the kinds of concepts, beliefs, and views that students command together with a better picture of the ways in which and the varied circumstance under which they are used. At present, much of the information is fragmentary and reflects in a preliminary way, how pupils operate with these views in classrooms or interviews. But it might well be that the view espoused is at least as much a reflection of the circumstances as it is of some uniform, underlying committment. What role do the notions of an animal, force, heat, motion, work, and so on play as the student engages the world outside of the classroom? Until we have a much better understanding of the particular views pupils espouse, and the role they play in relation to other views they hold and other things they say and do, we had best approach these studies with caution and tolerance, lest we fail systematically to understand them. It may turn out that it is we rather than they who have the wrong idea!

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"Aristotelian" Was Given as the Answer, But What Was the Question

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Introduction

Recent research by Champagne, Klopfer, Hewson and others has convincingly demonstrated that students encountering Newtonian physics in school, already hold ideas about how and why things move (Champagne, Klopfer, Solomon and Cahn, 1980). These ideas are incorrect when compared with Newtonian physics. Research has also been directed toward determining how such pre-instructional knowledge interferes with the learning of new ideas, how students use this knowledge to explain phenomena (Champagne, Klopfer and Gunstone, 1981), and the extent of the existence of these different pre-instructional ideas, in various populations (Champagne et al 1979, and 1980, and Hewson 1981). Further, ideas about the origins of such pre-instructional knowledge (Champagne, Klopfer and Anderson 1979), its resistance to change (Champagne, Gunstone and White 1982) and the factors likely to facilitate the learning of Newtonian physics (Champagne, Gunstone and Klopfer 1982) have been expressed. The implications of this research for the physics classroom are profound, where full consideration of pre-existing ideas in a given content area becomes an integral component of the teaching-learning interaction. A label describing this pre-instructional knowledge of students was introduced by Champagne, Klopfer, and Anderson in 1979, with a great deal of caution. This label, Aristotelian, only four short years later, is now widely used by other researchers (Fines and Leith 1980; Hewson 1982), often without caution. Further, a sort of tradition seems to be developing as information about pre-instructional ideas of students comes pouring in, that of naming the pre-instructional knowledge of students by an adjective from the history of science, for example, caloric (   ) and Lamarckian (   ). The purpose of this paper is to raise questions concerning the advisability of the continued use of such adjectives, specifically Aristotelian, without a concerted effort to understand whether or not it is an appropriate label for what it purports to describe. The History of Science provides instances of the crucial role of nomenclature in its progress, and provides guidance in terms of what would be considered good nomenclature. These guidelines will then be used to examine the appropriateness of the label, Aristotelian, from the aspects of the reasons for its use, pitfalls which could result from its use, and what it really means as a description of the pre-instructional knowledge of students.

Nomenclature in History

This matter of nomenclature is not a trivial one. There are many examples from the history of science where names of things actively hindered the growth of a science and conversely, where a careful consideration of nomenclature facilitated the growth of a science by rendering new ideas more objective and less controversial than they might otherwise have been. The choice of two such examples will suffice to make this point.

First, in a paper presented at the Royal Institution, in 1833, Michael Faraday stated, "I find the greatest difficulty in stating results, as I think, correctly, whilst limited to the use of terms, which are current, with a certain accepted meaning." He was attempting to describe his electrochemical research and his concern about appropriate nomenclature was twofold. On the one hand, he was concerned that new words not reinforce a particular electrical theory, since theory was highly debatable at the time; on the other hand, he felt that a crisp nomenclature was essential for clarity of thought and communication. He said, in regard to the existing terminology of "electro-positive" and "electro-negative" that, "these terms are much too significant for the use to which I should have to put them; for though the meanings are perhaps right, they are only hypothetical, and may be wrong; and, then, through a very imperceptible, but still very dangerous, because continual, influence, they do great injury to science, by contracting and limiting the habitual views of those engaged in pursuing it .". He continues, then, that in order to "avoid confusion and circumlocution", and to derive a "greater precision of expression" he engaged the linguistic advice of friends in the classics. With their help and the use of Greek roots, he coined the words electrode, electrolyte, cathode, anode, cation and anion. Since an electric current explaining the magnetism of the Earth supposedly flowed from east to west, cathode was derived, meaning "the way the sun sets" and anode, "the way the sun rises." By such denominations he was able to avoid classifying electrodes as positive or negative and supporting one or another theory about the nature of the electrodes and yet maintained the distinction between the electrodes, so apparent from experiment. By coining the word "electrode", to replace "pole", meaning "the way of amber" he avoided connotations of polarity or attraction, a subject of serious debate.

Faraday, then, coined names with the utmost care that they be neutral in respect of any of the competing theories of his time, including his own, but which more than adequately served the purposes of clarity and facilitation of communication.

The second example comes from an even earlier time, when the names of chemical substances were recognized as being an enormous hindrance to any classification of them. Practical chemistry had, by the mid-eighteenth century, yielded a bewildering variety of substances which were named haphazardly according to the whim of each chemist. Some names were alchemical, traditional and meaningless like "powder of Algaroth", and "flaming spirit of Saturn"; others described the substance variously like "magnesia alba", "oil of vitriol", "liver of sulphur" and "sugar of lead"; and others from people or places like, "Glauber's salt" and "Epsom salt". Around 1780, Guyton de Morveau, influenced by the efforts of Bergman in geology and Linnaeus in natural history, made an issue of chemical nomenclature, with its artificial creation of similarities and differences and its hindrance to progress. He attempted to devise a new system based on the constituents of a substance. In 1787, de Morveau, together with Berthollet, Fourcroy and Lavoisier published the "Methode de nomenclature chimique" using five guiding principles; principles used by Faraday and others to the present time.

Three of the principles are particularly applicable here. The second principle stated that names should, as far as possible, conform to the nature of things; the third that when no certain understanding of the nature existed, that a name expressing nothing, in compositional terms, is preferable to one which may express a false idea; and, the fourth, that new names are best coined from the roots of the most widely spread dead languages, being ancient Greek and Latin. It is recognized that the success of Lavoisier's contribution to chemistry was greatly enhanced by this major reform in nomenclature, and that the new pattern gave chemistry a clarity frequently lacking in other sciences (Ihde, 1964). Lavoisier himself wrote about "the impossibility of separating nomenclature of a science from the science itself" in his preface to "The Elements of Chemistry" in 1790. He also quoted the Abbe de Condillac in the preface, stating that "The Sciences have made progress because philosophers have communicated to their language that precision and accuracy which they have employed in their observations: In correcting their language they reason better .".

It also must be recognized that one of Lavoisier's glaring errors occurred because he named a substance not according to the objective principles, but to support his theory of its composition according to his own Oxygen Theory of Acidity. He renamed a green gas, derived from one acid and creating a different acid in water, oxy-muriatic acid gas, for his theory demanded that the gas be compound and contain excess oxygen. Sir Humphrey Davy, helped to secure the overthrow of Lavoisier's oxygen theory of acidity by persuasively demonstrating that the green gas contained no oxygen, and was not compounded. After de Morveau's principles of nomenclature, he then renamed the gas for a neutral characteristic, its color, and from a Greet root, as chlorine.

There are, then, precedents from history for the recognition that naming is not an activity to be taken lightly. That nomenclature, at its best, is as objective as possible and neutral in respect of a theory concerning that which is to be named, is clear. History, further, shows that when names, which are meaningful are applied without due concern, they can be a hindrance rather than a help. Perhaps now, when information about prior knowledge of students in science is burgeoning, is a good time to examine the naming of pre-instructional notions of children in this light.

Concerns About the "Aristotelian" Label

Aristotelian is a meaningful label, without scrutiny, it means from or like Aristotle. It might be instructive to ask if it was selected for this reason, because the student beliefs are in direct accord with what Aristotle believed. It is worth examining all the reasons for its selection, in particular to determine whether or not it is a label which to a large extent supports some theory or another, since the lesson from history is that such labels perhaps should be avoided. It is certainly worthwhile to resurface the reasons and provisos with which it was introduced by Champagne, Klopfer and Anderson in 1979, as well as to look at any changes that have occurred since then. Four different aspects of concern can be described.

When the adjective Aristotelian was introduced, it was written that "the foregoing description of the situation implies that the Aristotelian paradigm of the students is fully developed and articulated. Unfortunately this is an oversimplification. In many respects, the pre-instructional knowledge of many, but not all, of the students is more accurately described as "pre-paradigmatic" (Champagne et al, p. 31). It was also said that "To a large degree the rules of the belief system parallel the descriptive aspects of Aristotelian physics. Although the causal notions of Aristotle (which are often animistic) were not encountered in the students protocols" (p. 31). The authors wrote, "It is convenient to refer to the common sense belief system about motion as Aristotelian ." (p. 31), and later, "Aristotelian emphasizes the contrast between what they have and Newtonian ideas ." (p. 31). And in between all of this, it was written that, "It seems useful to view the students pre-instructional belief system and courses which target mechanics as competing paradigms which Kuhn has described in his work on scientific revolutions ." (p. 30). In summary, then, the name was introduced with recognition that it was not a completely accurate label, it needed much qualification regarding its meaning. Its use was justified on the grounds of convenience, the distinction it allowed between what it described and Newtonian ideas, and the existence of some parallel in students' beliefs with some aspects of Aristotle's beliefs. Throughout, the comparison between the scientific revolutions as described by Kuhn, and the process of coming to believe in Newtonian explanations on the part of individual students was actively drawn (p. 30-33).

More recently, as the label as become adopted, Hewson writes in 1981, "But other students in the group held an Aristotelian view of motion, namely that for an object to go faster, a larger force needs to be applied" (Hewson, 1981, p. 9). Pines and Leith, in 1980, wrote, "work showing Aristotelian conceptions of physics persist despite the efforts to introduce Newtonian mechanics" (Pines and Leith, 1980, p. 18), and Hewson, in 1982, writes, "An Aristotelian view of the relation between force and motion is very prevalent" (Hewson, 1982, p. 22). In each case, the adjective is used freely and without proviso. Champagne, Klopfer and Gunstone write in 1981 and '82, respectively, still with some caution, about ideas "which are generally more Aristotelian than Newtonian" (Gunstone, Champagne and Klopfer 1981, p. 27) and "the conceptualizations have features which are broadly Aristotelian" (Champagne, Gunstone and Klopfer 1982,p. 2). It appears that the label has been accepted as useful by the research community, without proviso, and that caution about its usage has almost completely disappeared. This point is the first cause for a closer examination of the label.

Secondly, in the same time period there have been some remarkable changes in the way cognitive constructs of the pre-instructional knowledge are envisaged. That is, although the propositional aspects of the knowledge being described have not changed, such as the relationship between force and motion, the description of those theoretical things in the minds of students has changed considerably. Again in 1979 (Champagne, Klopfer and Anderson), it was written that, "A characteristic of the pre-instructional belief system of these students is its loose structure, displaying little interconnectedness, it lacks overlying formalism" (p. 31). Today, however, the descriptive labels are "world view" (Champagne, Gunstone and Klopfer 1982, p. 2) or "alternate frameworks" (Pines and Leith, 1981, p. 18) and the inference is that students hold Aristotelian world views, or an alternate framework is an Aristotelian conception. There is an enormous difference between the images called forth by the phrases "loose structure" and "world view", or "little interconnectedness" and "framework". Aristotelian, then, describes not only propositional statements of beliefs of students but whatever it is that exists in the minds of children -- and this latter is theoretical. There is some justification for questioning the role of the label Aristotelian as it impinges upon the description of the theoretical constructs of cognition, and their hypothesized level of integration.

A third aspect which perhaps requires examination is that Aristotelian was introduced, and continues to be used along with comments about the interesting parallel which is described to exist between the growth of knowledge in an individual and that of Western science in history. This oft-mentioned interesting parallel has overtones of a recapitulation theory. Such a theory is a highly seductive one and has appeared through the centuries in one content area after another. Piaget has been often misconstrued in this aspect. The sheer number of times that it has been mentioned by a large number of researchers in Science Education, must mean that they feel that it is most noteworthy.

There are many ways in which a perceived parallel could come about, of course, without a strict recapitulation of one by the other. If indeed the parallel exists, it could be a meaningless coincidence, as the recurring hexagonal shape in nature, reflecting a common constraint on both. If, however, a parallel exists, and if it is thought to be meaningful, then surely some theory of cause of relationship is needed, to be crucially examined and tested. It seems reasonable, that adherence to some as yet unframed theory resting on some to-be-proven parallel of propositional beliefs, can do little but create confusion and is likely to set off a flurry of search on very flimsy grounds. The findings of cognitive psychology show that theory driven observations and explanations are not unusual. The phenomenon is noted among students who hold these different pre-instructional beliefs about motion (Champagne, Klopfer and Gunstone, 1981), as they observe and/or explain rates of fall of different objects by their belief system. It is, then, at the very least, plausible, that if this hypothesis of a parallel between the ontogeny of an individual's knowledge and the phylogeny of Western Science, exists, it could affect both the findings and the pattern of research. Regardless of whether researchers hold a revolutionary view of history, or an evolutionary view or a composite view depending on the content area, any meaningful parallel hypothesized to exist between ontogeny and phylogeny can be reinforced by labels from history, subtlely, and imperceptibly as Faraday described.

Aristotelian is a meaningful label and its use simply for convenience cannot be justified. Its use simply to draw a distinction between one set of ideas and Newtonian ideas cannot be justified either. Its meaning as historically preceding Newton is a dangerous one, resting as it does on some, as yet, unstated theory governing a perceived parallel between the growth of an individual's knowledge and that of Western Science. Its other meaning, of course, meaning from or like Aristotle is perhaps the major consideration. If one asks, in what sense are belief systems described as Aristotelian, Aristotelian, the best answer ought to be that students believe what Aristotle himself believed. Upon a careful analysis of this question, however, the simple answer is that they do not.

A Comparison of Student Beliefs With Aristotle

Firstly, the propositions believed by students which are described as Aristotelian will be examined. One set of four common elements among the variety of idiosyncratic personal belief systems of the students being investigated were recognized and described as Aristotelian by Champagne, Klopfer and Anderson in 1979. They are

1. A force, when applied to an object, will produce motion.
2. Under the influence of a constant force, objects move with a constant velocity.
3. The magnitude of the velocity is proportional to the magnitude of the force, any acceleration is due to increasing forces.
4. Without a force, objects are at rest, or if moving (because of (stored-up momentum while previous forces were acting) they are slowing down (and consuming stored-up momentum).

At other times these propositions were also designated Aristotelian, by Champagne and others.

1. Where there is motion, there must be a force acting.

and 2. When an object's speed changes, it is because the force on the object has changed (Champagne, Klopfer, Solomon and Cahn, 1980).

3. For an object to go faster, a larger force needs to be applied (Hewson, 1981).
4. Force determines speed (Gunstone, Champagne and Klopfer, 1981).
5. The greater downward force applied to the heavier objects implies that its speed of fall must be greater.

and 6. Objects are naturally at rest, in the absence of force objects don't move (Champagne, Klopfer, Solomon and Cahn, 1980).

All of these beliefs of students prior to instruction in Newtonian physics center around the causal role of force in producing motion, and the direct proportionality of that relationship. All of the experiments in which these beliefs of students were expressed were within the content area of motion under gravity, free fall, inclined planes, pulleys and so forth. Students, then, believe that motion implies force, or conversely force causes motion under the circumstances of motion under gravity. In fact, researchers described in students the creation of new concepts to explain observations or to justify their predictions under these circumstances, for example, a "gravity gradient" concept (Hewson, 1981). The force used by students to explain motion in these experiments was gravity. Champagne et al report that a central proposition in the reasoning of the student was that "the force of gravity on an object is roughly proportional to its speed in free fall" (Champagne, Klopfer, Solomon and Cahn, 1980, p. 61), and that "This proposition is similar to the Aristotelian conception that the force acting on an object determines its speed" (p. 61).

To turn, now, to Aristotle, he had decided views about the causes of motion when things fall downward, slide downward, or are moved because they are attached to an object moving downward. When objects fall toward Earth, whatever the circumstance, Aristotle believed categorically that no force was acting. He was so adamant on this point as to call motion caused by a force, by a different name than motion of falling without a force. The motion, because of a force, he calls violent motion, unnatural motion and compulsory motion to distinguish it from natural motion.

Aristotle believed that there were four basic elements in the Universe, earth, air, fire, and water, and he uses these terms in this metaphysical sense. In Book 8 of the PHYSICA, he asks the question, "How can we account for the motion of light things and heavy things to their proper situations?" (255b, 13). Their proper situations he took care to describe earlier in Book 8, light things which are for him fire and air, move upwards. He says, "Air is actually light and will at once realize its proper activity as such unless something prevents it. The activity of lightness consists in the light thing being in a certain situation, namely high up" (255b, 10). Heavy things for Aristotle are water and warth, and their natural motion is downward toward the whole Earth. In Book 4 he says "each of the simple bodies has a natural locomotion, e.g. fire upward and earth downward and towards the middle of the Universe" (214b, 15). He answers his own question about what explanation there can be for light things to move upwards and heavy things downwards in the sentence following the question in Book 8, by saying, "The reason for it is that they have a natural tendency respectively towards a certain position: and this constitutes the essence of lightness and heaviness, the former being determined by an upward, the latter by a downward tendency" (255b, 15). He finishes the paragraph by saying, "so it is clear that in all these cases the thing does not move itself, but it contains within itself the source of motion -- not of moving something, or of causing motion, but of suffering it" (255b, 29). He is painstakingly drawing the distinction between the natural movements of animals which move themselves, a violent motion or unnatural motion when something moves something else, like someone carrying bricks upward against their natural potentiality to move downwards, and the actualizing of the potential of the essences of lightness and heaviness to their respective places of rest in their natural sphere. It is difficult to fully understand what he means by the actualizing of the potential of the quality since motion includes growth, health, learning and a wide variety of other changes, besides change of place, for Aristotle. It is, however, abundantly clear that downward motion of matter for Aristotle, in the kinds of experiments discussed with the students, carried absolutely no connotation of force, no connotation of an attractive pulling from the Earth or anything which can be so construed. Motion of this kind for Aristotle is the actualizing of the potential of the quality of matter of which something is made. Thus in free fall situations, inclined planes and pulleys, to call a belief that force causes motion Aristotelian is incorrect.

Similarly, to quote Isaac Asimov, "Aristotle's theories said nothing about the manner in which the velocity of a falling body changed with time" (Asimov, 1969, p. 14). Further, for the "at rest" situation, if students believe that objects are at rest because no force is acting upon them, this is not a belief to which Aristotle subscribed. For him, objects are at rest when they have reached their proper situation, or equally likely they may seem to be at rest when they are actively being prevented from reaching that situation. In Book 8, Aristotle says that air may still only be potentially light, that is, not in motion, "for it may be that through some hindrance it does not occupy an upper position, whereas, if what hinders it is removed, it realizes its activity and continues to rise higher" (255b, 19). He goes on to say that "the thing in a sense is and in a sense is not moved by one who moves what is obstructing and preventing its motion, e.g. one who pulls away a pillar from under a roof is the accidental cause of motion" (255b, 23) and Sir William Ross footnotes that the real cause is the downward tendency of the roof. Thus Aristotle describes objects seemingly at rest, which are rather actively being prevented from moving to their real place of rest, either up or down, by some obstruction.

All of the other propositions described as student beliefs about the relationship between force and speed, like proportionality of speed and force, are not Aristotelian beliefs in this content area either, of course. Without analyzing them in the same detail since they are not applicable to the free fall situation for Aristotle, it is worth mentioning two points. First, in arguing strenuously against the existence of a void in Book 4, Aristotle describes, under a condition of unnatural motion, that "we see the same weight or body moving faster than another for two reasons, either because there is a difference in what it moves through as between water, air and earth, or because, other things being equal, the moving body differs from the other owing to excess of heaviness or of lightness" (215a, 25). The effect of the mediums on the motion is of equal import to the amount of heaviness or lightness qualities in the body. And secondly in Book 7 (250a, 1-10), when Aristotle discusses the proportionality of force in the context of motion, he is quite specific that if a force A moves object B a distance T in time D, then in the same time, the same force will move 1/2 of B, twice the distance. He is very careful to relate the proportionality of force to time, distance and size of object not to velocity. Further, Aristotle describes the case of 1/2 the force maybe producing no motion at all; so, the proportionality is not a complete one. Thus, even in a completely different content area than motion under gravity, for Aristotle, in discussing unnatural motion, his proportionality is not the simple one between magnitude of force and of velocity described by students. And again those beliefs of students are not Aristotelian.

To complete this portion on Aristotle's work, it should be recognized that difficulties seem to arise for several reasons, one of which is that 'kineo', the Greek verb to move, is a transitive verb, hence the seemingly laborious justification of how some things are not moved by a subject nor move themselves, but suffer motion as the actualizing of the potential of heaviness and lightness. A second is that mathematically speaking, Aristotle did not believe in division of one attribute, distance, by a different attribute, time, hence he allowed no connotation of velocity as that mathematical quotient. The carefully wrought descriptions of proportionality reflects this attitude. And thirdly, Aristotle was often not addressing issues which are faced by young people of today; this difficulty surfaces in attempting to respond to a rather different use of the adjective Aristotelian by Di Sessa who stated that, "For our purposes, we use the term to mean that objects simply move in the direction you push them" (Di Sessa, 1982, p. 41). Though it has been written by one historian that Aristotle must have conceived of a square cornered flight path for an arrow (Boas, 1966), Aristotle never described this. Further, he certainly was aware of the flight of an arrow, a javelin, or other projectile, was a noted scientific observer and was committed as a philosopher to saving the phenomena, i.e. explaining why things are as they seem. As such it would seem improbable that Aristotle would have described such an unnatural occurrence. It is one of the difficulties for historians that scientists in the past did not always address the issues that we would like them to have done; for example, Aristotle's thesis on up and down natural motion occurs not to explain falling objects, but to inquire into the nature of place, and Ross writes that "Galileo supposed Aristotle to be saying that heavy bodies would drop faster in a void than light ones" (Ross, 1956, p. 88), when really Aristotle was arguing that two contrary results obtain from two different points of view if one supposed the existence of the void, and, therefore, that the void cannot exist. Sometimes, things which are described as Aristotelian are rather the interpretation of an historian in content areas not specifically addressed by Aristotle, and, of course, this presents a real problem.

Summary

In summary, it has been shown, then, that the propositional statements of belief of students prior to instruction in Newtonian physics are quite unlike the beliefs of Aristotle himself. If this is so, can we justify using the adjective Aristotelian for such beliefs? If the meaning of Aristotelian does not mean like Aristotle, is it advisable to use it for convenience? If the real meaning is non-Newtonian, is its use likely to produce an error like Lavoisier's oxy-muriatic acid gas, and the danger of which Faraday was so wary? If the use of the label Aristotelian reinforces some hypothesis that ontogeny parallels phylogeny, in science knowledge, both the real existence of the parallel and a positive statement of the hypothesis should perhaps be attempted. Sufficient justification has been presented that without either of these, or a correction in nomenclature, we may find ourselves in the position of Charles Darwin who said, reflecting on the work of his grandfather, "I was much disappointed, the proportion of speculation being so large to the facts given" (Gruber, p. 76).

Therefore, after a concerted effort to understand what Aristotelian means when applied to the belief system of students prior to encountering Newtonian physics, it would seem that its use is inadvisable because it is incorrect.

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Misconceptions and Myths
Masquerading as Biological Facts

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If more than 95% of all scientists who ever lived are alive now, it is no wonder that the doubling time of scientific knowledge is just a decade. This explosive growth undoubtedly overwhelms us biology teachers. To sift and winnow the massive pile of information and arrive at what may constitute basic biological concepts is an overwhelming task even for the best among us. For this task the sources on which teachers depend are, of course, the numerous textbooks on the market. Indeed, writers of textbooks with patience and perseverance try to package for retail distribution this immense mass of information produced by the innumerable research scientists past and present. I do not intend to offend my colleagues by appearing to demean an intellectual activity by dividing us all into three categories, such as producers, purveyors, and consumers. Though as a practicing biologist, in a very narrow field, I may be a producer of a miniscule amount of knowledge, basically as a full-time pedagogue I am an avid consumer and an enthusiastic purveyor of the products of other scientists, often fascinated by what I retail.

Of course, we glorify and take pride in the practice and propagation of science, a self-correcting endeavor towards understanding the universe within and around us. But we often forget to tell our students that the scientific method we use is one of trials and *errors*. The most important misconception, or perhaps I should call it the myth of modern society, is that scientists are infallible. How many times have we heard said by our students and lay people that science, unlike humanities or art, consisted of unalterable "facts"--a word imbued with an aura of a religious dogma, tenet or doctrine or TRUTH with a capital T. Perhaps we teachers are just as guilty in the perpetration of this "cult." Why do we insist on true or false questions in our so-called objective tests? It is unfortunate that most often science is not taught the way science is. We teach very little history of science. We rarely train our students in inductive and deductive reasoning relating logic to the scientific method. We seldom introduce them to the importance of both the reductionist and holistic approaches in the pursuit of science. Without all this, how can we expect our students and citizens to understand the analytic and synthetic processes constantly at work in science? As it is, most of our students are confused and uncomfortable with scientific controversy, particularly our non-science majors. Science majors are almost religious in their fervor, with a disdain for the humanities, arts and other creative endeavors of the human mind. That the essence of science is controversy is not grasped by most. What is worse, we do not teach them how to identify a scientific controversy and differentiate it from a political or religious one. Our present costly engrossment with creationism is the result of our ostrichlike assumption that our modern society, as a whole, is scientifically literate. (Douglas Futuyma, 1983, *Science on Trial*: *The Case for Evolution*, Pantheon Books, NY.) C.P. Snow's warning about the two cultures is not just a thing of the past. Thus, there is an inherent problem in teaching science, especially biology, which deals with many multidimensional and complex concepts which have a direct impact on human mores.

In addition to the above mentioned built-in myth about science itself, we have also to contend with many more misconceptions and myths masquerading as scientific axioms. The persistence of such myths and misconceptions is due to several factors. Inherent in the development of the scientific enterprise is the inevitability of errors leading to misconceptions and myths. What a surprise it was for me when I read that Sir Francis Bacon himself was aware of this problem. He said, "The method of discovery and proof whereby the most general principles are first established and then intermediate axioms are tried and proved by them, is the parent of error and the curse of science." Alex Comfort (1969) quotes this in his book "The Biology of Senescence" when he discusses the numerous hypotheses dealing with the biological causes of aging, many of which are persisting to this day, despite evidences to the contrary. Such hypotheses in science may have originated as heuristic and/or speculative tools quite legitimate to the scientific method. Such intellectual tools, however, long outlive their usefulness and persist as intractable misconceptions or obscure myths. Such errors and intellectual cul-de-sacs acquire a pertinacious mystique of their own, relentlessly haunting us in textbooks and even in scientific journals. Thomas S. Hall (History of Physiology, 1975, p. 376) put it succinctly, "Named abstractions possess a notorious tendency to take on an illusory concreteness." What all this amounts to is that in every branch of science, there has to be frequent housecleaning. We want to believe that this is what textbooks are supposed to do. There was a time when textbooks were written mostly by savants who had acquired a considerable historical perspective in their fields of speciality. What is more, these scholarly writers had the humility to title their texts as "Introduction to Biology or Introduction to Entomology, etc." However, they too had their share of perpetuation of myths and misconceptions. Thus it is that the onus falls on our shoulders. I am glad as teachers we have recognized this need, as evidenced by this international seminar.

Not only do myths and misconceptions in the sciences present serious and often unidentified difficulties for the classroom teacher, but they also become a "drag" or stumbling block to the growth of science itself. History of science gives us numerous examples of the latter. W.P.D. Wightman (The Growth of Scientific Ideas, 1951, p. 5) said, "Ideas like persons are born, have adventures, and die. But unlike most persons they do not disappear from this mortal stage; their ghosts walk, often to the confusion of new ideas." My colleague Professor Randerson and I recently (1981) presented a paper at the Annual Convention of the National Association of Biology Teachers. In this paper entitled "The Rise and Fall of the Gene -- A Tale of Two Centuries," we traced the development of the concept of the gene starting from about the middle of the last century to the present. First, the paper dealt with a historical summary of changes in the concept of heredity and the possible implications of new discoveries. Second, we discussed the difficulties of teaching genetics at a time when the classical concept of the "gene" is so disputable that it may lose its integrity. Third, we examined the didactic use of the "story of the gene" by biology teachers to illustrate the processes in the development of scientific concepts. In all, we attempted to focus on recent developments in biochemical genetics and to reconsider our basic understanding of what a gene is.

The word "gene" was coined to denote a particulate unit of heredity, situated on a thread-like chromosome, a number of which compose the cell nucleus. The problem was relating this word to a manifest characteristic of an organism, such as the color of a person's eyes, being left-handed or right-handed, baldness, etc. Soon it became evident that really a gene determines the structure of a protein. Then came a discovery of the DNA structure and the knowledge of how a protein was built from the instructions coded in the DNA. All this complicates the understanding of the gene as the transmitter of basic characteristics and properties of all living things, including humans.

The concept of the gene has been one of the most exquisite theories in biological science. But today, as genetic research becomes more and more complex, the gene may become an antiquated concept. Thus the case history of the gene is one example of how inevitable errors accrue over time, in the development of scientific ideas.

Let me first clarify my use of the terms myths and misconceptions. I admit there is an element of arbitrariness in the criteria used for the categorization. Nevertheless, I find it useful to distinguish between two kinds of "errors" that we commonly encounter in science. I use the word *misconception* to describe those conceptual errors whose origins are traceable to the historical development of the sophisticated and esoteric concepts themselves and are therefore inadvertently nurtured by scientists, teachers and textbooks. Examples of misconceptions are, outdated and erroneous *ideas* that cling *atavistically* to concepts such as gene, mutation, species, type, etc. I will be examining some of these in greater detail presently, after I delineate the term myth. Widespread erroneous *beliefs* held by the society at large, related to complex biological concepts such as race, evolution, adaptation, intelligence, etc. are examples of *myths* that students and lay persons alike traditionally acquire from their homes as well as from the rest of the institutions of society, including, of course, their schools. I hasten to admit that as in all classifications, the line of distinction drawn between the terms myth and misconception is not a clear-cut one. There are some serious *misconceptions* which assume the characteristics and proportions of myths, when accepted as a credo by a large part of the esoteric scientific community itself. An example of such a misconception almost grown into a myth in biology, perpetuated in textbook after textbook is "All mutations are harmful to the organism." In a paper entitled "Mutation mumbo-jumbo" published in the March 1982 issue of the Science Teacher, we attempted to clarify the

concept of mutants and mutations and to try to redeem the concept from the bad press it has had for years. Among others, we made the following points:

1) Individual gene (point) mutations are not so rare. Practically every one of us may harbor at least one that was not present in either of our parents.
2) Though originally mutations were noticed in freaks and in induced abnormal individuals, ample evidence shows examples of point mutations with no deleterious or lethal effects, e.g., dozens of human hemoglobin variants.
3) If all mutations are harmful, there can be a dearth of raw material for descent with modification, i.e., evolution.
4) Mutation is an innate property of the DNA molecule.
5) "Usefulness" or otherwise of a mutation will be determined by the organism's environment in which the organisms live at the given time.
6) In the event of a change in the environment of the future, the not-so-useful or even "harmful" mutation of the present may be the saving grace of the species, while the "useful" ones of today may be "disastrous" in the future.
7) Accumulation of new genes and phenotypes in a given population may not be be such a slow phenomenon, and
8) Dominance and recessiveness of genes are relational properties and dominant genes are not predominant in a population nor are recessives rare and deleterious.

There are many more misconceptions that are associated with the gene. Let me just mention a few of them. So many textbooks still say a gene represents a trait, or character or feature. Here is an example from a latest textbook (Mader, Inquiry into Life, 3rd Edition, 1982); the statement that a gene dictates a trait such as height is double trouble. It is now quite clear that the term gene, if it is going to mean a particular section of the DNA molecule coding for a polypeptide can no longer be associated with tongue rolling or widow's peak, free or attached earlobes, etc.

Another idea, namely the "fitness" of individual genes, may be a useful reductionist tool in what Ernst Mayr calls beanbag genetics, but to my colleague and me, fitness of a gene, like the adaptive advantage of every single organ is not so meaningful in an evolutionary sense. By this we do not deny the existence of occasional individual lethal genes or genes conferring profound morbid effect, such as Tay-Sach's disease. Enough said about genes for now.

A misconception we have dealt with in another one of our papers is about species, entitled "The Importance of Being Earnest about Species Concepts" (In press -- The American Biology Teacher, 1983, Fall). We discuss here the common confusion regarding the biological species concept versus the typological species concept. The former is based on populational thinking whereas the latter stems from ancient Greek philosophical tenets. Nevertheless, the typological thinking is so persistent that it interferes with the teaching of the biological species concept. We also question in this paper another related but misconstrued concept, namely the wild type, used by geneticists meaning the commonest form, but by implication condemning all other variants as abnormal or uncommon without regard to populational differences.

Let us examine some myths now. Race is a biological concept based on populational thinking and therefore a statistical concept and no individual human being (for e.g.) can be accurately assigned to a given race. The sociological and biological concepts of race are based on entirely different criteria. The sociological concept of race, though apparently using biological characteristics, is in reality only using social, economic, and nonbiological factors such as geography, language, and customs. Only one or two unreliable biological or genetic characteristics either singly or together, according to convenience, are often used to clinch the sociological definition of race. Examples of such characteristics are skin color and hair texture or shape of the eye.

Take a single individual -- how can we assign him or her to a "race"?

Examples:

1) Skin Color - the darkest dark people in this world do not live in Africa, but in India, where people are generally classified as Caucasians. Shouldn't we call them black? I'm not sure if the Indians would like it, nor the Africans.

2) Hair Texture - kinky hair is associated with blacks. We all know many whites with extremely kinky hair. Are they white or black?!

It is apparent that when convenient politically and socially we use one or both of these characteristics to suit ourselves to fit our sociological preconceptions about an individual or a group. This myth should be a dead horse by now, but look at the excerpts from textbooks. For examples, "Blacks have more apocrine sweat glands". (Biology of Animals, by Cleveland Hickman, 1982 p. 588, 3rd Edn.), "Sickle cell anemia affects mostly black people", (Body Living Systems, by R. F. Oram, 1967, p. 188). We live in a society of abbreviated newscasts on TV and radio and journalese, which nurture the growth and persistence of such abominations. All this despite what so many scientists such as Dobzhansky and Ernst Mayr have so eloquently explicated. Let me end with a quote from Ernst Mayr (1968, Science and the Concept of Race, ed. by Margaret Mead et al, p. 104).

"I am reminded of an apocryphal story about the American newspaperman who went to Haiti and had an interview with the President. They started to talk about Haiti and its population, and most indiscreetly the American newspaperman asked the President what percentage of the people were white. And the President of Haiti said, "Oh, about 95 per cent". The American newspaperman looked a little puzzled and said, "Well, how do you define White?" And the President of Haiti said, "How do you define colored?" And the American newspaperman said, "Well, of course, anybody with Negro blood is colored." Said the President: "Well, that's exactly our definition, too: anybody with white blood is white."

One can see how deeprooted this concept is in the psychosocial history of society, when one reads textbooks from decades ago such as the Stanford Biology text of 1929 (General Biology, by Burlinggame, et al, 1929, p. 526-7) and the text from last quarter of the last century (Man and Apes, by S. Mivart, 1874, p. 5).

There are several myths associated with the concepts of evolution and adaptation. I will not ennumerate them all here, particularly the popularly held ones. However, one that often pops up in textbooks and classrooms is that "Evolution is always striving for perfection". This is a variation of the Herbert Spencer phrase "survival of the fittest". If so, how do you explain to the students the evolution and presence of the sabretoothed cats of the Pleistocene? How do you define Perfection? Then there are questions such as, "Are we going to lose our little toe or the vermiform appendix?" These questions are vestiges of an erstwhile era, when biologists were preoccupied with the concepts of use and disuse of organs, and speculated on the adaptive advantage of each and every organ of an organism.

One more dead horse that we have to keep flogging is the problem of the inheritance of intelligence. Many lay persons, and even some scientists, remain convinced that specific, identifiable genes dictate the level of human intelligence and that the number and quality of these genes in a person can be evaluated. The arrant nonsense which passes for science is alarming because it can lead once again to the use of biology as a social weapon and to a revival of Social Darwinism, which was prevalent during the first half of the 20th Century.

Again a myth of a bygone era keeps cropping up over and over again. We published an article in the Science Teacher, February 1983, which unfortunately was flippantly titled by the editor "Smart Genes, Stupid Science." This article is an effort to show that almost every one of the 46 human chromosomes is involved in the development of the nervous system and therefore human intelligence. The evidence points to the fact that an abberration of almost any chromosome can adversely affect nervous system development by disrupting metabolic pathways or by interfering or interacting with other genes.

In conclusion, let me share a few thoughts on what we teachers can do to reduce the prevalence and perpetuation of misconceptions and myths of biology. First and foremsot, authors of textbooks must exercise more care 1) to scrutinize statements that are on the verge of dogmatic generalizations, and 2) to scrupulously avoid statements that have attained the status of adages. Teachers of biology should be aware of the perpetuation of such misconceptions and myths through the teacher's guides supplied with textbooks; these guides not only tend to be doctrinaire but also have true/false test questions. Teachers should pay special attention to all-inclusive and all-exclusive statements.

Students should be taught to understand that we also learn science when we demonstrate that a widely held idea is erroneous; this is the falsifying principle of science at work. Students must be trained in the skill of recognizing fallacious arguments based on erroneous premises, even if impressive figures of means, frequencies and correlation coefficients are used in the article or text. Numbers and apparent quantification do not automatically make the information scientific.

It is also essential that we train students to understand that a scientific theory is time-tested and has the highest place in the order of scientific ideas. It has withstood repeated attempts to repudiate it, and has attained predictive value. Therefore, it is accepted by the majority of scientists as the best possible generalization of hitherto observed phenomena.

Finally, I am sure we all realize that misconceptions are easier to correct but myths which are longstanding, especially those with societal reinforcements are much harder to combat. But in the neverending challenge of science teaching, we should not be afraid to play the role of the Man from La Mancha.

Classroom Conceptual Change : The Lesson to be Learned from the History of Science

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Some educators fully recognized, as early as fifteen years ago, that the study of students' preconceptions and their role in later learning of relevant topics constitutes a research area of high significance (Ausubel, 1968). However, it was not until this year that this research area received outside recognition. Such recognition has been given by the editorial board of Scientific American. In the April 1983 issue, they included a paper by Michael McCloskey entitled "Intuitive Physics". This paper reports on a misconception in mechanics that prevails among high school and college students before and even after relevant instruction. McCloskey argues that

> "...The misconception appears to be grounded in a systematic intuitive theory of motion that is inconsistant with the fundamental principles of Newtonian mechanics (p. 122) ....The intuitive theory bears a striking resemblance to the pre-Newtonian theory of impetus (p. 123).

Later on, McCloskey claims that his subjects "recapitulated the medieval impetus theory". (Such a claim has an attractive character since it implies that we can unfold the history by studying the development of the present individuals. It reminds the old attractive statement, saying that "ontogeny recapitulates phylogeny.")

McCloskey is not the first to report about the tenacity of students' preconceptions, despite instruction (Archenhold, et al, 1980; Brumby, 1979; Champagne et al, 1980; Clement, 1979; Deadman & Kelley, 1978; Erickso, 1980; Gilbert et al, 1982; Gunstone & White, 1981; Helm, 1980; Johnstone & Kellet, 1980; Osborne et al, 1983; Viennot, 1979). He is also not the first to suggest the analogy between students' cognitive growth and the history of scientific ideas. Many researchers in science education have already proposed in their reports that such parallelism exists.

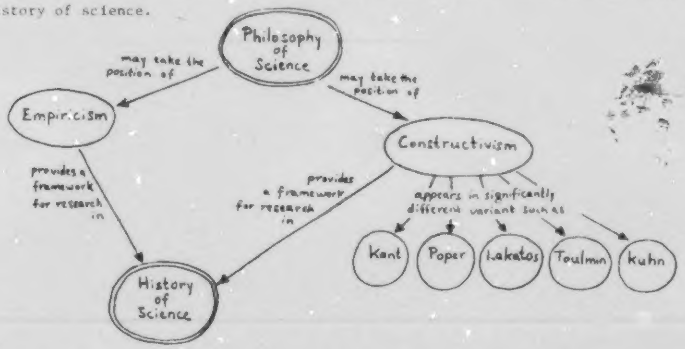
I assume that most science education researchers who point to this analogy believe that it can be potentially helpful for focusing our insight into the processes of science learning. Unfortunately however, many researchers do not develop the ramifications of the analogy, and go no farther than making the claim that a striking parallel exists. In many cases, the suggested parallelism serves only as a decorative element -- it does not comprise a substantial component in the theoretical approach to the analysis of findings.

A challenge for science education research is to arrive at a deep understanding of the dynamics of conceptual change, from "naive" preconceptions to the intended "scientific" conception, as it takes place in the classroom. Once we meet this challenge we will be able to devise appropriate teaching strategies to foster the desired conceptual change.

In this paper I build on the assumption that "the analogy" can indeed contribute to our attempt to meet the aforementioned challenge. I intend to argue that this potential contribution will not be realized unless one deliberately explicates the relevant sensible and useful aspects of "the analogy". Before developing my argument I should make it clear that this "analogy" ought not to be carried to the point of absurdity. I do not believe that the student of science simply recapitulates the history of science; there are, however, parallels that are worth examining. The issue is what is to be learned from these parallels in particular and from research in the history of science in general.

Which approach to the history of science to adopt?

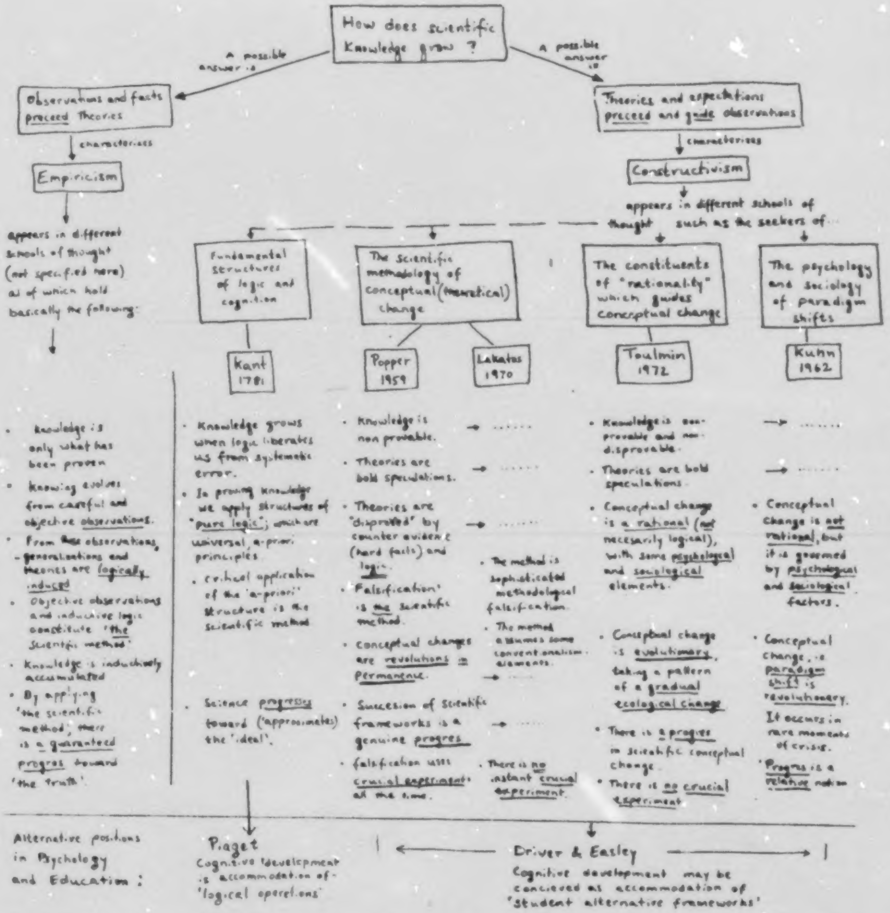
Before pursuing the implications that an analogy to the history of science may bear for improving our treatment of conceptual change in the classroom, one has to clarify for oneself what kind of history of science he/she adopts. The history of science is not a field dominated by a monolitic approach. Rather, there are as many "histories" of science as there are rival philosophies of science. The map in Figure 1 indicates some of the different philosophical schools that yield different accounts of the history of science.



Philosophy of Science
may take the position of
Empiricism
may take the position of
Constructivism
provides a framework for research in
provides a framework for research in
History of Science
appears in significantly different variant such as
Kant
Poper
Lakatos
Toulmin
Kuhn

Figure 1. Alternative philosophical frameworks for the study of the history of science.

The chart in Figure 2 compares some of the basic presumptions of each of the rival schools of philosophy.



How does scientific Knowledge grow ?
A possible answer is
A possible answer is
Observations and facts preceed theories
characterizes
Empiricism
appears in different schools of thought (not specified here) all of which hold basically the following:
Theories and expectations preceed and guide observations
characterizes
Constructivism
appears in different schools of thought such as the seekers of...
Fundamental structures of logic and cognition
The scientific methodology of conceptual (theoretical) change
The constituents of "rationality" which guides conceptual change
The psychology and sociology of paradigm shifts
Kant 1781
Popper 1959
Lakatos 1970
Toulmin 1972
Kuhn 1962
· Knowledge is only what has been proven
· Knowing evolves from careful and objective observations.
· From the observations, generalizations and theories are logically induced
· Objective observations and inductive logic constitute 'the scientific method'
· Knowledge is inductively accumulated
· By applying 'the scientific method', there is a guaranteed progres toward 'the truth'.
· Knowledge grows when logic liberates us from systematic error.
· In proving knowledge we apply structures of "pure logic"; which are universal, a-priori principles
· critical application of the 'a-priori' structure is the scientific method
· Science progresses toward ('approximates') the 'ideal'.
· Knowledge is non provable.
· Theories are bold speculations.
· Theories are "disproved" by counter evidence (hard facts) and logic.
· 'Falsification' is the scientific method.
· Conceptual changes are revolutions in permanence.
· Succesion of scientific frameworks is a genuine progres
· falsification uses crucial experiments all the time.
→ ......
→ ......
→ ......
· The method is sophisticated methodological falsification.
· The method assumes some conventionalism elements.
→ ......
→ ......
· There is no instant crucial experiment.
· Knowledge is non-provable and non-disprovable.
· Theories are bold speculations.
· Conceptual change is a rational (not necesarily logical), with some psychological and sociological elements.
· Conceptual change is evolutionary, taking a pattern of a gradual ecological change
· There is a progres in scientific conceptual change.
· There is no crucial experiment
→ ......
→ ......
· Conceptual change is not rational, but it is governed by psychological and sociological factors.
· Conceptual change, i.e. paradigm shift is revolutionary. It occurs in rare moments of crisis.
· Progress is a relative notion
Alternative positions in Psychology and Education :
Piaget
Cognitive development is accommodation of 'logical operations'
Driver & Easley
Cognitive development may be concieved as accommodation of 'student alternative frameworks'

Figure 2. Alternative philsophical frameworks and some of their main presumptions.

* The reader is asked to consider that this chart is a first attempt of a non-expert in the Philosophy of Science.

At this point the readers' attention is called for noticing one of the essential differences between these schools. I shall try to show how this difference takes shape in the various approaches that science educators relate to students' conceptions (which are at variance with the "scientific" ones).

Notice in the chart that there is a significant difference between each of these schools in the way they conceive what "knowledge" is and how "knowledge" has been achieved in the history of science. For the empiricists, knowledge is only what can be proved through observations and logic and it is inductively accumulated.

A conception that is at odds with the accepted scientific one is simply wrong and it deserves the label 'misconception'. The sources for misconceptions are always either faulty observations or a misapplication of logic. The way to correct misconception in students should be, therefore, teaching them to carry out better observations followed by careful logical procedures.

For Kantians, knowledge is constructed by the mind through our a-priori mental structures. Since our a-priori structures are principles of "pure logic", given to us as a divine gift, appropriate application of these principles should lead us to an approximation of the "true" knowledge (though we can never know the "truth"). For kantians, Newtonian physics is the evidence that appropriate application of logic can yield a high approximation of the 'ideal'. The representatives of the Kantian school in the field of psychology and education are Piaget and his followers. Piaget was probably the first to propose the parallelism between the history of science and children's conceptions about natural phenomena. Piaget (1962) states:

> "... For science to shift from a geocentric to heliocentric perspective required a gigantic feat of decentration [overcoming egocentric perspective]. But the same kind of process can be seen in the small child."

In his Genetic Epistemology (1970), he makes it even clearer that what he means by the parallelism is the similarity between both paths of development of logical thinking.

> "... The fundamental hypothesis of genetic epistemology is that there is a parallelism between the progress made in the logical and rational organization of knowledge and the corresponding formative logical processes. Of course, the most fruitful field of study would be reconstituting human history -- the history of human thinking in prehistoric man. Since this field of biogenesis is not available to us we shall do as biologists do and turn to ontogenesis".

For Piagetians, the source of students' conceptions that are at variance with the scientific one is either being at a developmental stage in which the required logical operations have not been developed yet, or simply misapplication of logical operations. Since for Piagetians (following Kant) logic is absolute, universal, and the primary indicator of rationality, students' odd conceptions are basically misconceptions which should be taken care of by better logical treatment.

As we move on the map from Kant to the right side we come across different philosophical schools which all recognize that conceptions and theories are basically bold speculations that do not evolve from logical considerations. However they differ substantially in the way they see how logic is applied latter on in the process of conceptual change. We have here on one end Popper (1959), who assumes that science progresses through a succession of frameworks. The frameworks themselves are bold speculations, but the decision to reject a framework (a theory) is based on 'hard' facts evaluated by 'hard' logic (falsification). On the other end, Kuhn (1962), holds that the very act of proposing a paradigm (a framework, a theory) is speculative (not logically based); moreover, Kuhn asserts that the very act of conceptual change, or paradigm shift, is not logically based. Kuhn holds that historical conceptual change should be studied in the realm of sociology and psycology.

Driver and Easley (1978) were probably the first ones, of those interested in the area of students' conceptions, to point explicitly to the relevancy of studying students' preconception/misconception and connect this to the issues between different philosophies of science. In their very significant paper they brought to our awareness that Piagetians approach students' odd conceptions by assuming some deficiency in logico-mathematical operations. They also show in their paper their bias to the philosophical variants within the range of Popper to Kuhn. This bias is expressed in the new term that they proposed, which is - students' alternative frameworks. This term is to substitute for the term misconception which bears a negative connotation, and as a metaphor, is more appropriate for an empiricist view.*

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*Though they do not explicitly refer to Kuhn in their paper, their title -- Pupils and Paradigms", reminds immediately Kuhn's major term.

It is a fact that among the recent philosophers and historians of science, Kuhn is the most widely known among laymen. Kuhn's idea, of the "paradigm shift", that takes place in rare moments of crisis, has captured people's attention. Today, many people in various fields use Kuhn's model uncritically (Pollie, 1983) not knowing that among philosophers of science Kuhn's view has been seriously criticized (Lakatos & Musgrave, 1970). I have no intention to even approach this issue here. However, I would like to draw the reader's attention to the fact that since Kuhn published his book (1962) there have appeared several alternative philosophical positions. Two very significant ones are Lakatos' (1970) and Toulmin's (1972). Popper himself has in recent years (1982) changed his original position and he stands now closer to Toulmin and Lakatos. My contention is that if we believe in the potential value of the analogy between the history of science and students' conceptions we should study all these alternatives, and explore the lessons they bear for science educators.

Several questions for the "history of science"

In the following section I will present several basic questions that are asked in the field of history of science and which can be similarly asked in our field of science education. I propose that the answers given (either by past or future research) by historians of science may be considered valid and useful in education. I build on the assumption that history of science is the history of conceptual change and that conceptions (frameworks/paradigms) guide our perceptions and observations, and (needless to say), our interpretations and conclusions. I assume that many of the problems our students have in understanding scientific ideas and theories are due to the difficulties they have in changing their preconceptions. For each of the following questions I shall add just a few comments regarding historical and educational contexts. The questions are directed to different aspects of the same phenomenon. This means that there is an overlap. An answer to one question actually will be a partial answer to another question.

1. Is conceptual change guided by some logical arguments or by some sociological-psychological factors?

This is obviously the issue between Kuhn and the other Neokantian thinkers. Kuhn will probably be the only one who will welcome the sharp dichotomy suggested in the question. Others will have more complex answers.

In terms of education, the answer may influence the strategies we devise to initiate and encourage conceptual change. Do we want to place more emphasis on the social context of the classroom in planning strategies toward conceptual change? What can be learned from the nature of historical debates that can help us observe, understand and initiate classroom debates regarding alternative conceptions. Classroom case-studies, such as those conducted by Nussbaum and Novick (1982a) and Minstrell (1982), could be enhanced by broadening the study in this area.

2. If speculating a theory is a rational (but not necessarily logical) process what components-factors are involved? For those who hold that conceptual change (discarding one conception in favor of a new one) is a rational process what component-factors are involved?

This issue concerned mainly Toulmin (1972) who has tried to propose a model in which conceptions (networks of concepts) are gradually changed following a pattern of ecological change. The question remains what constitutes the "pressure" for the "natural selection" of concepts.

In the area of science education, the papers by Posner et al. (1982) and Hewson (1982) are attempts to answer this question.

3. What are the metaphysical roots of the dispute between particular theories? In what way does metaphysics play a role in the dispute? What happens to metaphysical beliefs as the dispute between the particular theories is resolved?

Superficial accounts of historical developments of scientific ideas tend to report discoverers names, dates of discoveries and what old idea was believed before and what new idea replaced it. They do not deal with the most fundamental assumptions of each belief which in the final analysis becomes a matter of its metaphysical foundation. For instance, the centuries-long dispute between proponents and opponents of 'atomism' was rooted in several metaphysical assumptions. One of them had to do with alternative ways to conceive the "nature of space". Space could be conceived as "the place of bodies". (Aristotele). According to this school of metaphysics there is no space if there are no bodies (Aristotele believed in a finite space which ends at the outest sphere). Evolving from this metaphysics is the belief that vacuum is impossible. "Nature abhors vacuum". The proponents of "atomism" have held thoughout history that space is independent of the bodies that it may contain. Therefore space may be infinite and not only is a vacuum possible -- it is an essential element in the atomists conception of the structure of nature. (This metaphysical conception of space allowed Newton to conceive motion along infinite straight lines.)

Recent studies by Nussbaum & Novick (1982b) and by Engel & Driver (1981) report on students' strong belief that a vacuum somehow exerts a suction force on close by materials. These materials "rush in" and nullify the vacuum. The fact that this belief is very tenacious despite instruction raises the suggestion that it is well rooted in certain metaphysical grounds. It is for the historians of science to show educators how metaphysical assumption influence particular theories and how metaphysical assumptions change.

The map in Figure 3, taken from Nussbaum & Novick (1982b), represents an attempt to pursue the alternative metaphysical assumptions that may be the basis for various particular students' "misconceptions" regarding the particulate nature of air.

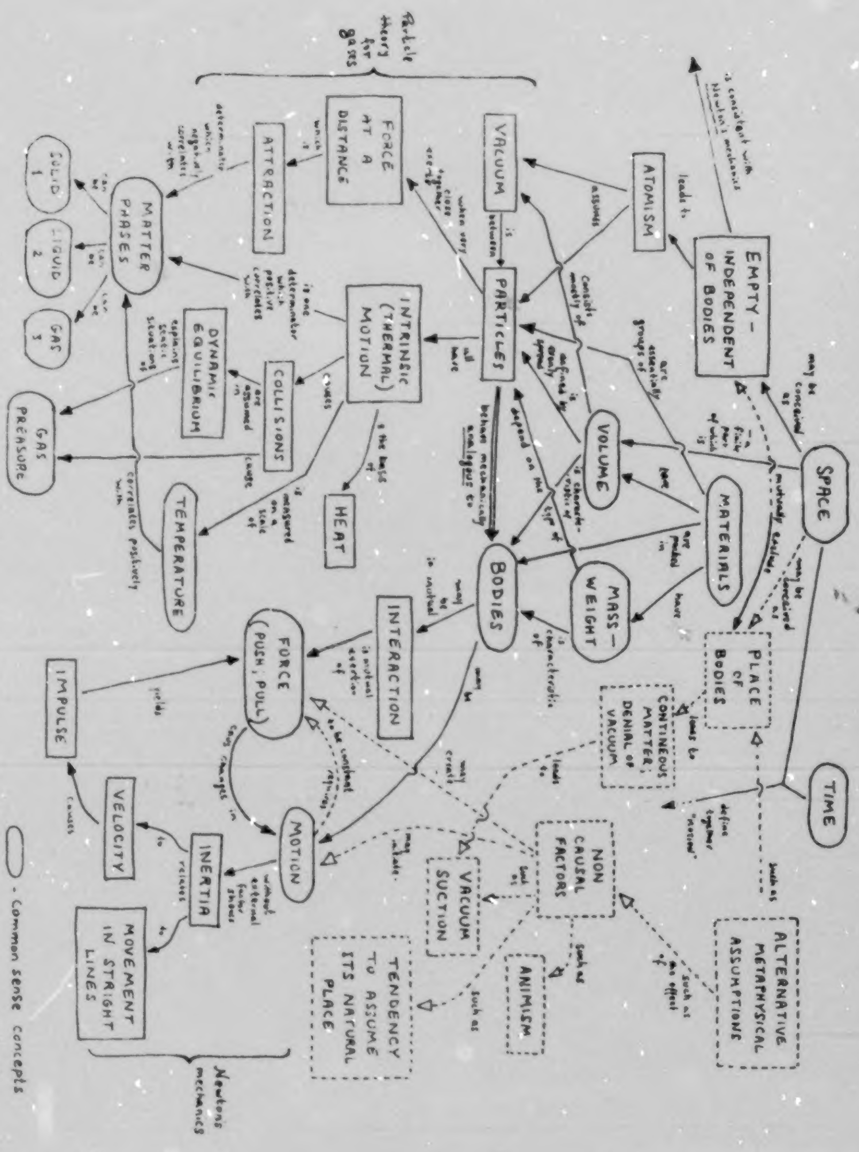

SPACE
TIME
EMPTY – INDEPENDENT OF BODIES
ATOMISM
VACUUM
PARTICLES
FORCE AT A DISTANCE
ATTRACTION
INTRINSIC (THERMAL) MOTION
MATTER PHASES
SOLID 1
LIQUID 2
GAS 3
DYNAMIC EQUILIBRIUM
COLLISIONS
GAS PRESSURE
HEAT
TEMPERATURE
VOLUME
MATERIALS
MASS – WEIGHT
BODIES
INTERACTION
FORCE (PUSH; PULL)
IMPULSE
MOTION
VELOCITY
INERTIA
MOVEMENT IN STRAIGHT LINES
PLACE OF BODIES
CONTINUOUS MATTER; DENIAL OF VACUUM
NON CAUSAL FACTORS
VACUUM SUCTION
ANIMISM
TENDENCY TO ASSUME ITS NATURAL PLACE
ALTERNATIVE METAPHYSICAL ASSUMPTIONS
Particle theory for gases
Newtons mechanics

Figure 3. Concept Map Analysis of Alternative and Scientific Frameworks.

○ - Common sense concepts

□ - Theoretical constructs

4. Is conceptual change an "evolutionary" or "revolutionary" process? Are there conceptions which lend themselves to change more drastically (as a gestalt shift) and other ones which lend themselves only to a gradual change (as ecological succession)?

In historical research there is a need to trace the line of transformations of ideas, including those that occurred between generations and those that occurred within an between individuals currently working in different places. Documents of the communication between scientists and private notes are important sources for this issue. One aspect of this issue is the question about the validity of the notion of "crucial experiments'. Are "crucial experiments" indeed the turning points where conceptual change occurs. The parallel issue in education is quite clear. Can we expect a fast conceptual change in classroom situations? Is it reasonable to expect a strong influence of "a crucial experiment". Toulmin, for instance holds that global conceptions never shift all at once but change gradually through changes of its constitutents, i.e., particular concepts. Many studies report on some kinds of "mix conceptions" that may represent classroom parallels to Toulmin's historical description. The findings of my earlier studies seem to support Toulminian description in classroom context. Figure 4a, taken from Nussbaum & Sharoni-Dagan (1983), presents group distribution profiles of three different age groups. The categories for classifying students are the various notions that students held about the earth as a cosmic body. The full analysis of those notions may be found in Nussbaum (1979). Here I shall only point out that each of the five notions represents a change of one element (a proposition connecting two concepts) out of several, at a time. The frequency profile at different age levels suggests that gradual change (evolutionary) has taken place in the group over time (four years). Figure 4b shows the same phenomenon of a gradual change in the same group of students (second graders) before and after instruction.

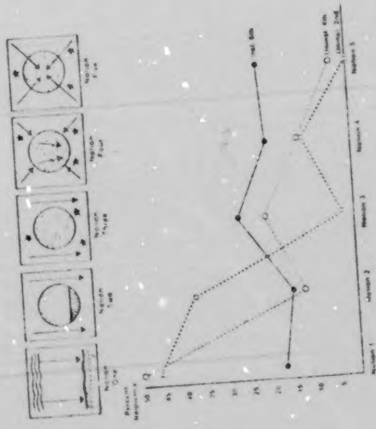


Figure 4a. Frequency profiles of children's alternative conceptions (notions) of the earth at various age levels, with or without formal instruction.

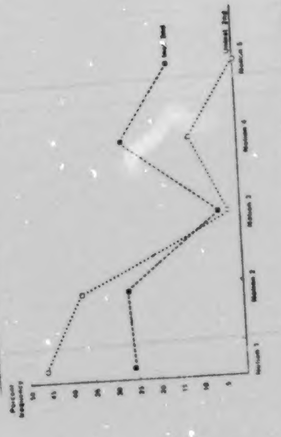


Figure 4b. Frequency profiles of children's alternative conceptions (notions) of the earth, before and after formal instruction. The two profiles are of the same group (second grade) (from Nussbaum and Sharoni-Dagan, 1983).

Figure 5, taken from Nu[illegible] gradual change in the [illegible] of air. In this Figure alternative [illegible] nature of air are listed.

SAF(a)	· completely continuous matter - no differentiation
	a1 · Continuous [illegible] a2 · aggregate of particles, no vacuum
SAF(b)	· particles in a vacuum · no inherent particle motion · particles retain bulk (macro) properties such as: b1 · particles expand on heating b2 · gases rise when heated · vacuum creates suction
SAF(c)	· particles in a vacuum · inherent particle motion which increases on heating · particles retain bulk (macro) properties when heated (particles expand; gases rises) · vacuum creates suction
SAF(d)	· particles in a vacuum · inherent particle motion which increases on heating · particles do not retain bulk (macro) properties when heated -- they do not expand or rise · vacuum creates suction
ScF	· as in SAF_d, except that -- · vacuum does not create suction

Figure 5. A Taxonomy of Student Alternative Frameworks (from Nussbaum and Novick, 1982b)
SAF-A Student Alternative Framework
ScF-A Scientific Framework

Figure 6 (a,b) illustrates a follow-up of two students' conceptual change through a series of ten lessons (four week periods) on the particle model of air. The records suggest that conceptual change may take an evolutionary pattern in which preconceptions gradually incorporate single elements from the new conceptions while relevant single elements of the preconception are discarded. It should be recognized that any teaching course consists of sequenced steps. Therefore, it may seem that any course must have a built in pattern for $\overset{a}{/}$gradual change. The interesting point about the findings is that although different lessons dealt sequencially with different elements of the new conception, students' conceptual change lagged behind the instructional sequence. (See figures 6a, b on pp. 14-15.)

This slow gradual (evolutionary) change should not surprise us if we accept the view which holds that great scientists of the past changed their conception gradually. Figure 7 reminds us that Dalton had the particle theory without its kinetic component. Figure 8 reminds us that Joule believed that particles expand while heated (although on highly sophisticated gounds). Figure 9 reminds us that Maxwell included "ether" particles which filled up the space between the material atoms. (See figures 7-9 on pp. 16-17.)

5. What is the mutual influence between the colloquial language, technological terms and the conceptual change?

Words change their meaning in different contexts. Words change their meaning in different places and historical periods. New conceptions provide new meanings to old expressions and create also new terminology. New technology also brings with it new terms and expressions. The interaction between these factors could be a promising topic for historical research. New technical terminology may be carried over to the non professional public, causing a gradual conceptual change. Such conceptual influence may be spread out and into other disciplines. Some examples are the terminology and ideas of Darwin and of Freud, which are used today by non professionals as well. There is no doubt that Darwin's ideas and Freuds's ideas not

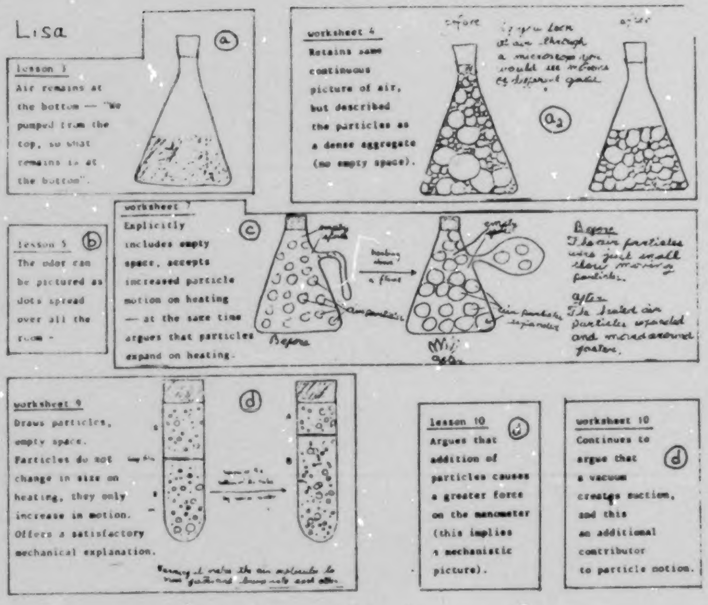
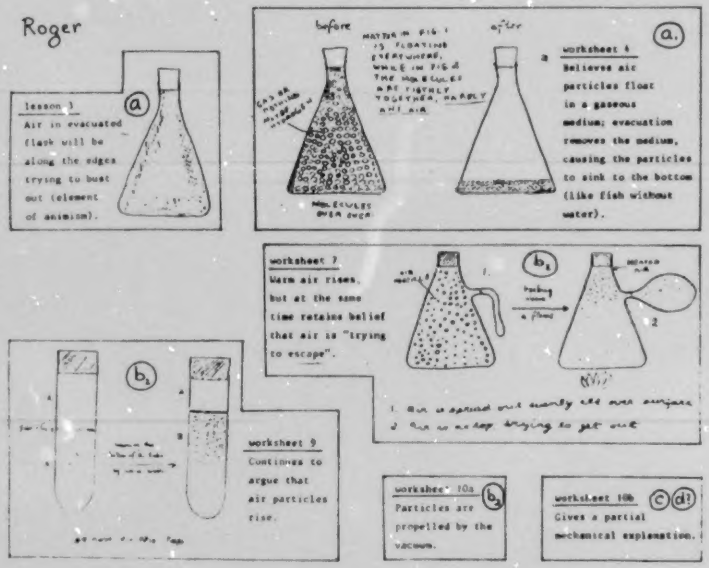

Lisa
lesson 3
Air remains at the bottom — "We pumped from the top, so that remains is at the bottom".
a
worksheet 4
Retains same continuous picture of air, but described the particles as a dense aggregate (no empty space).
before
after
a2
lesson 5
The odor can be pictured as dots spread over all the room.
b
worksheet 7
Explicitly includes empty space, accepts increased particle motion on heating — at the same time argues that particles expand on heating.
c
Before
After
worksheet 9
Draws particles, empty space. Particles do not change in size on heating, they only increase in motion. Offers a satisfactory mechanical explanation.
d
lesson 10
Argues that addition of particles causes a greater force on the manometer (this implies a mechanistic picture).
worksheet 10
Continues to argue that a vacuum creates suction, and this an additional contributor to particle motion.
d

Figure 6a. A follow up of one student's conceptual change (Nussbaum and Novick, 1982b)


Roger
lesson 3
Air in evacuated flask will be along the edges trying to bust out (element of animism).
a
before
after
worksheet 4
Believes air particles float in a gaseous medium; evacuation removes the medium, causing the particles to sink to the bottom (like fish without water).
a.
worksheet 7
Warm air rises, but at the same time retains belief that air is "trying to escape".
b1
b1
worksheet 9
Continues to argue that air particles rise.
worksheet 10a
Particles are propelled by the vacuum.
b3
worksheet 10b
Gives a partial mechanical explanation.
c d?

6b. A follow up of one student's conceptual change (Nussbaum and Novick, 1982b)

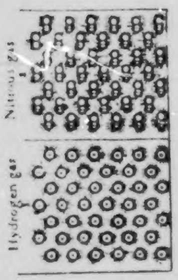


Fig. 1 Two drawings by John Dalton of the structure of gases (a) oxygen and nitrogen (taken from this Journal ...) (b) hydrogen and nitrous gas ... (taken from A New System of Chemical Philosophy, vol 1, pt 1, (1810))

Figure 7. A drawing by John Dalton of the structure of gases (1810). In Dalton's view gas particles repel each other until they are evenly scattered. At this point they reach equilibrium and they remain stationary.

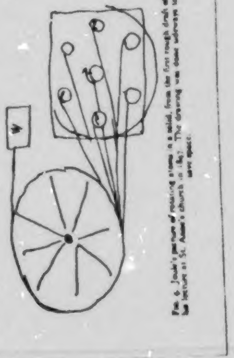


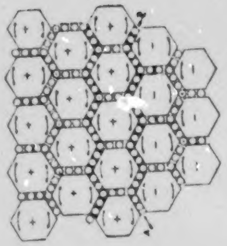
Fig. 6 Joule's picture of rotating atoms in a solid, from the first rough draft of his lecture at St. Ann's church in 1847. The drawing was done ...

Figure 8. Joule's Drawing of Rotating Atoms in Solid. A model which assumed atoms expansion when heated (1842).

From Philosophical Magazine (4) 21, 281 (1861).

[Nowadays, we present electromagnetic theory in an abstract way, but this was not the method of the innovators. Maxwell began by making a model of the aether, composed of vortices of sub-molecular size, all rotating in the same direction so as to produce the circulation of the magnetic field. In the spirit of the age he took the model very seriously.]

I have found great difficulty in conceiving of the existence of vortices in a medium, side by side, revolving in the same direction about parallel axes. The contiguous portions of consecutive vortices must be moving in opposite directions; and it is difficult to understand how the motion of one part of the medium can coexist with, and even produce, an opposite motion of a part in contact with it.



The only conception which has at all aided me in conceiving of this kind of motion is that of the vortices being separated by a layer of particles, revolving each on its own axis in the opposite direction to that of the vortices, so that the contiguous surfaces of the particles and of the vortices have the same motion.

In mechanism, when two wheels are intended to revolve in the same direction, a wheel is placed between them so as to be in gear with both, and this wheel is called an 'idle wheel'. The hypothesis about the vortices which I have to suggest is that a layer of particles, acting as idle wheels, is interposed between each vortex and the next, so that each vortex has a tendency to make the neighbouring vortices revolve in the same direction with itself.

Figure 9. Maxwell's Tiny Particles of Aether. (1861).

only influenced other disciplines but also influenced the laymen who gradually incorporated the terminology of those grand theories.

Citizens in a society are consciously or unconsciously exposed to scientific information communicated to them intentionally or unintentionally. There is little chance of preventing a person from being exposed to information. Word meaning in different contexts and other language influences can be a significant focus for science education research.

Concept map of various factors and their possible influence on conceptual change

In Figure 10 I describe, through the device of a concept map, factors and relationships which may be studied by historians of science in order to explain historical conceptual changes. This map includes the main factors which probably be considered as relevant by different 'constructivists'. (Empiricist do not recognize the pehnomenon of conceptual change as is meant in this paper.) Various schools of constructivists differ in the degree of relevancy to the process of 'conceptual change' which they assign to each factor. Each school relates different magnitudes of influence on conceptual change to different factors.

The intention of this paper was to develop the argument that the study of conceptual change in the history of science has a lesson to those who have interest in classroom context. The map in Figure 10 includes also some labels in dash-line frames. These labels are there to demonstrate in a visual way that the same factors may be considered in the study of conceptual change in classroom context. Good research of the classroom has to be evolved from some theoretical assumption and hypothesis. I hold that research in the history and philosophy of science can help us arriving at such theory provided that the analogy is carefully considered. I have brought it up earlier in the paper that the study of the alternative schools in the history and philosophy of science can be an important step in constructing a model to explain and to achieve conceptual change amongst the students of science.

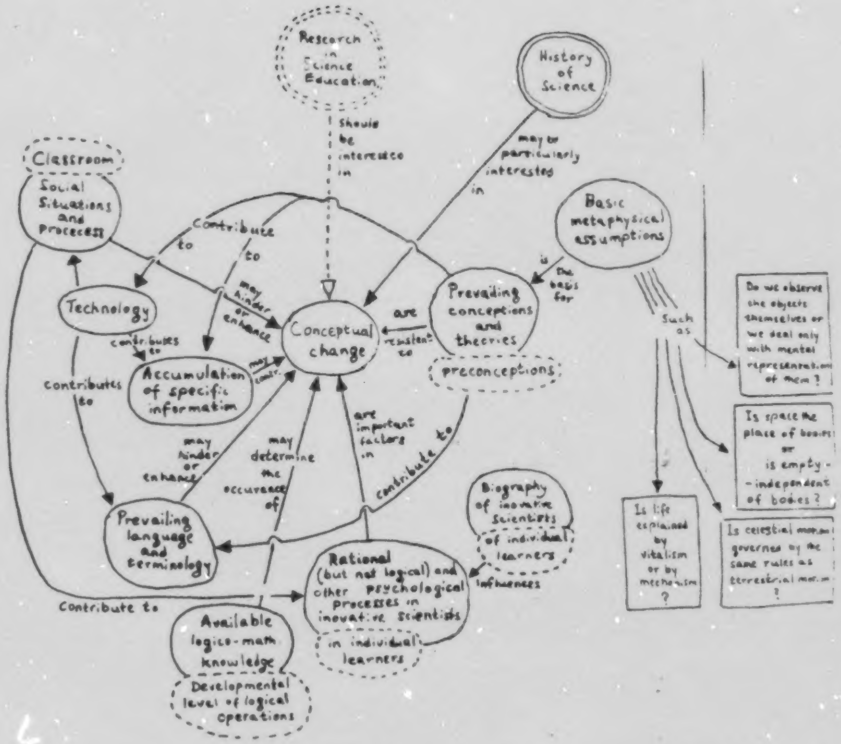

Research in Science Education
Should be interested in
History of Science
may be particularly interested in
Classroom
Social Situations and Processes
Contribute to
to
Basic metaphysical assumptions
is the basis for
Technology
may hinder or enhance
Conceptual change
are resistant to
Prevailing conceptions and theories
preconceptions
contributes to
Accumulation of specific information
may contr.
contributes to
may hinder or enhance
may determine the occurence of
are important factors in
contribute to
Prevailing language and terminology
Biography of inovative scientists
of individual learners
influences
Rational (but not logical) and other psychological processes in inovative scientists
in individual learners
Contribute to
Available logico-math knowledge
Developmental level of logical operations
Such as
Do we observe the objects themselves or we deal only with mental representation of them ?
Is space the place of bodies or is empty - - independent of bodies ?
Is life explained by vitalism or by mechanism ?
Is celestial motion governed by the same rules as terrestrial motion ?

Figure 10. Concept Map of Possible Factors and Relations that May Concern Researchers of Conceptual Change.

A Concluding Remark

At the beginning of this paper, I commented that variants of the statement "ontogeny recapitulates philogeny" are attractive because they leave the impression that by studying 'ontogenesis' we can unford and reconstruct the not manipulatable history. I suggest that the contribution of studying parallels will be mainly in enhancing our understanding of present processes by understanding the past and not vis versa.

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Alternative Conceptions of the Tentative Nature of Scientific Knowledge

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INTRODUCTION

Scientific knowledge is characterized as being tentative, i.e. of an experimental nature, uncertain, subject to change. History of science documents many alterations in the facts, concepts, theories, and laws of every scientific discipline. In line with the historical evidence, one goal of science education is to promote understanding of the nature of scientific knowledge and its tentative character. In a survey of students taking science at a midwestern high school, Rubba (1977) found that 30% of them believed that scientific research activities reveal absolute, incontrovertable truth. In two separate pilot studies for the present research, I found evidence among advanced placement high school students and, to a lesser extent, among college students of a belief in scientific knowledge as immutable. Perhaps a similar belief in the absolute correctness of scientific knowledge is held by citizens who become disillusioned with or cynical toward science, especially when errors or theory changes are announced in mass media.

In this paper I will present some data from interviews with college biology students on their beliefs about the nature of scientific knowledge. Emphasis will be on students' conceptions of the tentative character of scientific knowledge, and, within that topic, of the nature of observations in science.

In addition to providing a data base for developing practical approaches to promoting an accurate view of scienc among students, this research contributes to theoretical issues in learning. Within the conceptual change theory of learning (Posner et al., 1982; Strike and Posner, 1982), a person's beliefs about the nature of knowledge, the epistemological commitments, may be an important factor in what and how he or she chooses to learn. For example, if scientific knowledge is thought of as infallibly arising from observation, a person might study science by memorizing facts and might further expect to be able to absolutely prove hypotheses by the scientific method.

THEORETICAL BACKGROUND

Why is scientific knowledge tentative, fallible? How is it that theories change? To answer these questions it is necessary to consider theories of how scientific knowledge comes to be -- epistemology of science. Science texts commonly provide only step-by-step descriptions of "the scientific method" which are, at best, a superficial treatment of what some scientists do some of the time: observe, hypothesize, test, accept or reject the hypothesis, and so on. This approach is primarily procedural and avoids crucial issues of epistemology (Levison, 1976). Philosophers of science, however, focus a great deal of attention on epistemological dimensions of science.

Some of the relevant epistemological issues and questions include, for example, the nature of observations. How does a scientist decide what to observe? What counts as a relevant and valid observation? Other issues are the nature of objectivity in science, the nature of the connections between theory and observation, and the questions of whether a scientist is discovering laws of nature or imposing them on nature.

Immediately following publication of Thomas Kuhn's revolutionary book Structure of Scientific Revolutions (1962), issues in epistemology of science became highly controversial in the philosophy literature. The controversy centered on the problem of the role of theory in observation. Kuhn's view of science was in opposition to the view of the logical empiricists who were the leading theorists at the time. Out of this scholarly ferment has come a new epistemology of science, one which is enjoying increasing acceptance among philosophers and science educators * (though for some philosophers the dust is still settling). The new view of science is sometimes referred to as conceptual change theory.

Rubba's finding about students' belief in absolute truth, coupled with the cynical attitude of many citizens toward science; and my experience working with students in investigative biology laboratories indicated to me that there may be misconceptions or alternative conceptions of the nature of scientific knowledge. The philosophy of science literature provided at least two different perspectives on this problem, that of the logical empiricist and that of the conceptual change theorist. These two views of science formed the basis for questions used in interviews with college biology students in which they commented on issues in epistemology of science. Let's look briefly at some issues from the two philosophical viewpoints.

SELECTED ISSUES IN EPISTEMOLOGY OF SCIENCE

The epistemological issues of interest to me included those in which what we think about the character of knowledge is linked to what we think about some facet of scientific methods. For example, if observations are thought of as direct, accurate sensing of an object, then what one says when verbalizing the experience (i.e. the fact) is thought of as being true in an absolute sense. However, if observations are thought to be limited by what the observer already knows, then the fact cannot be absolutely true.

The following facets of epistemology of science were considered in this study: the nature of observations; the nature of perception; the relationships between experience and knowledge; the nature of interactions between theory and observations; and the ways in which changes in scientific knowledge occur. These facets all relate to the central problem of epistemology:** What is the nature and basis for truth of knowledge?

All empiricists deal with this central problem by defining knowledge as that which is known to be true in the absolute sense. Their philosophies must provide a basis for infallibility, and a mode of reasoning that leaves minimal room for error. Conceptual change theorists, on the other hand, view knowledge as fallible and historical. Their theories must account for the historical facts of conceptual change, and must redefine rationality.

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* I am basing this claim on the increasing number of articles on the "new" philosophy of science that can be found in journals for teachers and for educational researchers, particularly since about 1978. See The Amer. Biol. Teacher, The Sci. Teacher, School Sci. and Math., School Sci. Rev., Science Education, J. of Research in Sci. Teaching. Further, at least at the annual meetings of Nat. Assoc. for Research in Sci. Teaching for the last 3 years, the number of people discussing the new view of science as a possible solution to the problem of teaching about scientific knowledge and method has been increasing.

** Brown (1977) contrasts logical empiricism with conceptual change theory in his book Perception, Theory and Commitment: The New Philosophy of Science. My presentation of the two philosophies summarizes some of his main points.

The logical empiricists: Empiricists believe that experience is the only basis for knowledge. Observation is a process of accurate perception of reality. Sensory experience thus leads directly to true observational fact. The connection between the observer and the real world is direct. It is in this concept of the direct connection that empiricists establish a basis for the infallibility of knowledge. A corollary to this is that experience and the observational facts which result from experiences are theory independent.

With this foundation for absolute truth, logical empiricists employ symbolic logic and probability theory as their tools of reasoning. The rules of logic work like an algorithm in that they provide a way of reasoning that maintains a high degree of the truth integrity of observational facts. The result of application of such rules is true propositional knowledge. Probability theory is required because the logical empiricists rec[illegible] that conclusive empirical verification of propositions is impossible (the old"all cats are black"problem). Probability is used to assess the degree to which observations confirm propositions. This is seen in statistical hypothesis testing.

Given these views of experience and reasoning, the history of science according to logical empiricists, would be one of an accumulation of immutable facts, proven hypotheses, and theories which are built from hypotheses. All propositional knowledge would have withstood the empirical test and would have a high probability of being true. Changes in scientific knowledge would occur only rarely and then because of new evidence. The new data would not change the concepts (which are only one step removed from true facts, but would change the truth of propositions containing those concepts.

The conceptual change theorists: The "new" philosophy of science redefines the general principles of logical empiricism. Truth in not seen as infallible. Experience with observables is not a theory-independent activity. Observed facts are not seen as indubitably true. Legitimate reasoning processes are expanded beyond logic and into the arts of deliberation.

In conceptual change theory, observations take on a different character because the prior knowledge of the observer is taken into account. An example from Brown illustrates an effect of prior knowledge on perception.

> A chemist in the neighborhood of a steel mill will smell sulfur dioxide and will gain a great deal more information about what is happening to his body and his environment than will a child who smells only rotten eggs. Both observers smell the same thing. (p. 83)

In conceptual change theory, perception is taken as "seeing as". To see an object as something is to identify it and this requires a background of knowledge. (Empiricists would say that observation is seeing, not seeing as.)

In addition to conferring meaning on observations, prior knowledge directs and limits the observer's attention. Theory thus not only guides the observer to what is relevant, but limits what is observed. For example, an early theory of disease causation in plants was that diseases are spontaneously generated by the plant. With this theory it is irrelevant to search for external agents of disease (microorganisms), or to try to understand how diseases spread. Observations of diseased plants were limited to characterizing the morphological changes, or to documenting the locations of diseased plants. With a different theory of disease, for example the germ theory of disease, it becomes relevant to observe microorganisms, their dispersal, and the processes of infection.

In conceptual change theory, the relationship between experience and knowledge is not one of direct correspondance. Experience is still a vital part of the knowledge making process, but is not the basis for infallible truth.

Theories, according to a conceptual change view, are not built up from proven hypotheses. Rather, they develop within a historical context, within a subject matter and as a result of interplay between old theories and new observations. Changes in theories come about for a variety of reasons, an important one being that anomalies become overwhelming and the theory no longer adequately accounts for experience. The concepts themselves change, not only the propositions which include them. This is possible because concepts are thought to develop from theory-laden observations, rather than from infallible contact with reality.

METHODS

A survey containing 29 items about scientific knowledge was developed, pilot tested and revised several times. Each item of the survey was designed to reflect one of the two theories of scientific knowledge which were derived from the philosophy of science literature. In addition to serving as a way to quantitatively sample students' responses to each item over time (Waterman, 1982) items from the survey provided structure to short individual interviews with 29 students who had previously responded

to the survey. Each student was given five survey items (which were selected by a matrix sampling technique (Sirotnik, 1974)), and was asked about each item as follows:

> What did item XX mean to you?
>
> How did you interpret item XX?
>
> Please rephrase item XX into your own words.

Additional probes for students' interpretations of specific words or phrases in the items were used as needed. Although students were not at any time directly asked about their personal beliefs about any item, nearly all students volunteered their own opinion on the issues.

Subjects were a subset of the total sample of 364 undergraduates (80% first year college students) who were enrolled in both the lecture and lab courses of the Introductory Biology sequence for science majors at Cornell University. All students were interviewed in the spring semester, several months after the first administration of the survey.

Analysis of interviews: For each of the 29 survey items, there were interview segments embodying the comments of five different students, for a total of 145 interview segments. The analysis was done on an item-by-item basis. Three questions were asked of the interview segments for each item:

1. Did the item appear to be understandable?
2. What was the range of interpretations of the words of the item?
3. What positions did students hold on the issues covered by the item?

Answers to the first two questions provided additional information about the validity of the survey items. It is the answers to question three that are presented in this paper.

Students' positions were extracted from their interview comments, were described on an item-by-item basis, and were documented with quotes from the interviews. This procedure led to a process of generalization in which several recurrent themes running through the interviews were noted.

To illustrate the analysis, an interview segment from one student is shown, followed by the summary of the interpretation of the item and of the student's position regarding the item. The numbers in parentheses at the end of the interview segment refer to a particular student (first four digits) and his or her comments about a specific item (next two digits).

> Item 19. Scientific knowledge is an accumulation of facts and proven statements.
>
> Well, I kind of saw underlying that (item) people falling into the trap of thinking that everything in science is proven and factual There's not too much hypothetical... things like that, or models that are there because they work for that period of time, but they're supposed to be improved or worked upon. That's the way I saw that.
>
> (WHAT DID FACT MEAN TO YOU?)
>
> Well, when you see "fact" you kind of assume that it's unquestionable, it's pretty much proven and there's no question of doubt on it. And also proven statements, the two sort of go together. (1362-19)
>
> Interpretation: Sees the item as a "trap" for people who think everything in science is proven and factual.
>
> Position: The view presented in the item is limited. It should also include hypothetical, theoretical knowledge, models being worked on.

RESULTS

Students' comments on the tentative character of scientific knowledge seemed to follow three general themes. A very few students held strongly to a view that scientific knowledge is infallible. The remainder acknowledge that there are limits to the truth of scientific knowledge and qualified that view by one of two general lines of reasoning: either because of the limitations of science and human sense organs or because it consists in models which humans use to understand the world. These three themes were most evident in comments made in response to statements about the nature of knowledge and how it changes. Responses to items about observations, however, included very few comments about the role of theories and models in observational activity. Comments about observations will be reported first.

Responses to four items on objectivity and observations and to one item on the nature of human perception were summarized. The items are:

25 Data and observations are objective.

33 Scientists' observations are affected by the ideas they have about their subject.

30 Scientific knowledge is objective because scientists are trained to clear their minds before making observations.

39 Many apparently objective observations are interpretations of what is sensed.

On perception:

18 Knowledge of the natural world is the human perception of the world.

Students responded to the items on objectivity of observations in one of two general ways: they said either that observations are (or should be) objective or else that observations are not/cannot be objective. On the former position several students gave evidence of believing that observations are objectively made, but then are subjectively interpreted (0273-25, 1837-25, 0273-39, 1243-33). The following quote from 0273 on item 25 illustrates this position.

> ....A lot of times observations can be - they're done objectively but they're interpreted subjectively. ....Just like when we did the bee study last semester. I was in a group of six, and we all had opposite papers. Same data and everything, but we all came to different conclusions about the bees.

Other students say that observations should be objective (0740-36, 2344-34, 1836-36) but that sometimes scientists are biased and fudge their data (1980-36, 1956-25, 1983-33, 0504-33, 1980-36). The following excerpts are typical of this position.

> The data and observations aren't always going to be objective (i.e., neutral). They should be, but every once in a while you're prejudiced or your opinion is going to creep into your observations. (1956-25)

> Well, maybe what scientists might feel is objective is actually they're going on intuition, feelings instead of just looking at the data and analyzing it. ....Like when you have a feeling something is right - I just tend to believe that. Like you're doing a study and you know which of the results should come out a certain way, but they don't. You push to get the results to come out the way you feel. ....can become biased without you knowing it.

The following two excerpts are from students who say that observations are objective within limits. This position differs from the previous one in that the neither the claim of absolute objectivity nor the claim of inherant subjectivity is strongly made.

> ....So, I think that whenever you take data it's as objective as possible but it's not the ultimate objectivity. ....Even when you're trying to be as objective as possible, sometimes subjectivity just comes in there. So it (item 25) can't always be true. (0273-25)

> I don't know that observations are always objective. They're pretty close to being objective, but I think you can always put your own interpretations into things. And, like, especially if you have some idea of what something should come out to be, you tend to fudge a little bit, I think. (1837-25)

Students use several different arguments to support the claim that observations can not be objective. These arguments center on the human aspects of the observer, either the influence of his or her preconceived notions (e.g., 1836-36) or background (e.g., 0349-36) or the uniqueness and limitations of human sense organs (e.g., 0349-36, 0273-25).

> I think it's impossible for a scientist (to clear his or her mind before making observations) because the only reason they start to investigate something is because they have some preconceived notion. (1836-36)

Student 0349 covers all three arguments in his/her explanation of why scientists are not able to be objective.

> Sometimes when you look at an experiment, not only are you influenced by your hypothesis (so) that you may overlook certain things, or may look for certain things that may not be there, but your basic training also influences the way you look at things. And sometimes that will distort the actual picture. If you're looking at something that nobody's seen before, and it could be another explanation for the phenomenon, but you're looking at it in a different way, basically it has to do with your background.

Students' responses to item 18 on human perception of the world shed a little light on what the students perceived to be human limitations in science. All interviewed students agreed with the idea that what we know about the world is limited by humanness. They accounted for this and for the consequence that knowledge is not necessarily true by two different sorts of reasons. The first is based on the idea that organisms differ in their ability to sense the environment (1618-18, 1243-18). For example, bees' eyes and dogs' ears both work in different ranges of wavelengths and frequencies, respectively, than do human receptors for light and sound. Further, there may be individual differences among humans. Because of these differences in sense receptors, any knowledge that is claimed cannot be the absolute truth. This theme recurs repeatedly in interviews on other items.

The second position on human perception has to do with the influence of thought and/or prior knowledge on perceiving. For example, student 0819 says " ... your perception can be changed if you know different things, ... the object is relative. Whatever it is changes from person to person between what they know and what they don't." This theme of the role of thought on knowledge also reappears throughout the interviews.

Other items from the survey generated comments on the general characteristics of scientific knowledge, how it grows and changes. These, perhaps more than the others, revealed students opinions about how it is that scientific knowledge can be tentative.

On the scope and limitations of scientific method as a means of finding out about the world (items 21 and 23*) all but one of the responding students said that final understanding of reality is unobtainable. The one said that people can know things if they're here (e.g., digestion in humans) but we can't know other things because they're not here (e.g., evolution) or because evidence is missing (1211). Two major positions pervade the majority of answers: science and evidence are limiting versus limits of model-like knowledge. On the first, students say that you "can't be sure of the final truth because someone else will come up with another question or other observations and prove you wrong" (2022-23), that reality "is all blocked up by everything we don't know" (0819-23), that one can only increase the probability of knowing things (0347-23), or that "scientific method isn't that perfect" (1634-21).

The people who talk about knowledge being limited to models of reality give two sorts of reasons. The comments of student 0504 on item 21 illustrate one of these:

> "....You can never know exactly what's going or
> because you can't tear a cell apart like an en
> and put it back together. But science tries t

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21 Scientific method will eventually let people learn the real truth about the natural world and how it works.

23 We can never be sure we know the final truth, but it is a goal of science to get as good an answer as possible.

> come up with....close as possible models that it
> can".

In this case, models are thought to be constructed because of the limits biology imposes on finding out. The other position is that because we are human, the best we can do is to make models.

> "We have no one to tell us what the truth is directly. We can only postulate and theorize what we think the truth is, and that's where the scientific methods come in" (1310-21).

All of the students interviewed on item 41 agreed with the statement that "Theories and models are products of the human mind and may or may not accurately represent reality." Once again the two themes emerged when students explained why reality cannot be reached. One group used the argument of the limitations of science (1836, 1243) and of human perception (which includes the sense organs (1310) and prior knowledge (1243)). A typical sort of response was that of student 1836:

> There are some things in real life, like the DNA model, we don't know that it works exactly like that, but the model fits all the evidence we have and therefore it is very useful and it may in fact reflect reality....but you can't really be sure until you actually see that happening (enzymes unzipping the DNA molecule)....a direct observation, which we can't make.

The other group of students regarded theories and models as aids to "bring it about better in human minds where they can understand the concept they've developed themselves" (0347-41) or "to help (people) understand reality more, they make models and theories" (1238-41).

Interview excerpts based on responses to two of the questionnaire items on growth of knowledge are included to show the range of positions students hold on this issue. The items were:

32 Theories are made up of proven hypotheses

38 New theories originate in the constant interplay between current theories and observations.

On item 32, all the responding students qualified the word "proof" in one of several ways ranging from "in science, proof means something occurs with a high probability" (1836) and "proven in the sense that it is repeatable, workable" (1982), versus only temporarily proven because of human and technological limitations (1634) or the flat statement that "nothing can be proved" (1618).

Several different 'mini-accounts' of growth of knowledge appear in the students responses to this item. For example:

> A hypothesis is just more or less a guess, an educated guess. And theories are one step above that. Like, if your hypothesis keeps holding up time after time, then it becomes a theory. (1608)

This student's comment is very similar to accounts given in school books, very traditional. The next student had a different idea, that theories can come from observations (physical phenomena) or you can make them up without observations and just substantiate them later. This is a somewhat more sophisticated view than the one previously illustrated.

> Sometimes you start out with a theory and you find hypotheses and data to fit it. Like Einstein with his theory of relativity. He didn't figure it out as physical phenomena. He figured it out and later physical phenomena proved he was right. So, it could work both ways. (1836)

The following quotation shows how another student handled the tentativeness of theories, in somewhat of a rote manner, but at the other extreme from 1608. Here, because theories are not provable they are made up to fit the facts.

> (The course lecturer) has finally knocked that into my head. ....nothing can be proved, nothing can be proved. So, proven hypotheses, well you can't really prove it. ...a theory is not proven. It is just something that you're trying to make up to fit in all the facts. You can't prove it. (1618)

On item 38, the same student (1618) continued the theme that since a theory is not provable, it will keep changing. Now, s/he adds that it changes because of new evidence. Student 0504 gives essentially the same account for the interplay of theories and observations. That is, first, a theory, then new observations which, if incompatible with the theory, serve as bases for changing it. Neither of these students elaborated on whether or how theories affect observations, only on how observations affect theories.

In contrast, student 0276 emphasized theories as the foundation on which to build and change knowledge. Further s/he said

> Maybe there's just one little part of the current theory that's wrong. That's when they go to change it and the whole thing.... evolutionizes to a new theory. That's my only explanation as to how new theories arise. I think nowadays everything in the physical sense has been explained in one way or another. ....The only way new theories are going to originate is from building up and testing (with) the observations until they (the old theories?) are proved false.

Once again the range of positions on issues of the origin of theories and the growth of knowledge is broad, including both strong empiricist views as well as more conceptually oriented views. People believing in the tentative character of scientific knowledge seemed to fall into two groups: those who believe knowledge is tentative because of equipment and sensory limits, and those who believe knowledge is tentative because it is what we think.

CONCLUSIONS

Generalized positions held by students on the three philosophical issues of the nature of knowledge, growth of knowledge and nature of observations were summarized and three recurrent themes were found in students' interpretations. A few comments indicated belief in an absolutist view of knowledge - that there are things that can be known without doubt.

Most comments, however, indicated belief in a tentative character of scientific knowledge, but for two different sorts of reasons: the limitations of technology and/or sensory limits; or the notion that knowledge is theoretical and as such is subject to change. These three themes were evident throughout the interviews, but on questions of the truth of observations the conceptual view of knowledge was quite rare. Very few students made comments about the theory-guided and -limited nature of observations. Students tended instead to hold to stronger empiricist views and accounted for subjectivity in observations by dishonesty or by subconcious bias on the part of scientists. Such notions need to be countered with better information about bias and the nature of limitations to objectivity. Having a belief that it is possible to make theory-independent observations may be an obstacle to students' acceptance of the tentativeness of scientific knowledge, since objective observations could be seen as giving rise to true (absolutely) facts.

The widespread belief in absolute objectivity of observations (as determined in this study) suggests that it would be worthwhile to develop instructional activities and approaches that would focus explicitely on observations and on the implications of theory-laden observations for knowledge claims resulting from the observations.

Data such as those presented here can serve as a foundation for subsequent research into possible interactions between students' beliefs about epistemology in science and the ways they learn science. For example, the survey on which the above interviews were based was used with 364 biology students in an attempt to determine epistemological positions regarding science: i.e. did students agree more with items reflecting an empiricist view or a conceptual change view? One preliminary finding was a correlation between course grades in an introductory biology course and epistemological position. This sort of result suggests that it might be fruitful to pursue this question of the interactions between beliefs about knowledge and curriculum.

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Educational-Developmental Psychology and Curriculum Development: The Case Heat and Temperature

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At the 1983 meeting of the Society for Research in Child Development, one of us (Strauss) was struck by the co-occurence of both a richness and what appeared as an abberation of what cognitive developmental psychologists are doing and drawing from. He couldn't help but be struck by how many fields contemporary developmentalists draw from: (1) biology and, in particular, embryology and evolutionary theories as metaphors for developmental psychology, (2) mathematical and statistical models, such as in decision theory, Markovian chains, etc., (3) computer sciences, such as in processing models like production systems, and (4) philosophy, especially theories of mind and knowledge. One of the things that makes cognitive developmental psychology very interesting today is that anyone with inclinations towards these diverse areas can find a place for him/herself. This certainly points to a richness of what theorists and experimenters see as

impinging on their field. And, from our point of view, this is all to the good.

But along with this richness comes a very peculiar and, for us, disturbing aspect of what it is that developmentalists do not appear to be spending much time on; i.e., children. Now this will surely seem strange to many since a quick glance at journals in developmental psychology indicates many studies that describe how children behave and respond to this task and that or in this situation or that. But as we see it, the children being tested in those studies are the proving grounds for models that are developed independent of children. In other words, not much seems to spring up from children themselves.

Now the reader may be asking him/herself why we would be making such a point since, of course, we should draw from models that are from allied disciplines. Should it be otherwise? Our answer is that in addition to these models, we should be asking where the child enters the picture so that we can supplement the models about development. Given our predilections, it is no wonder that we think that the place where developmental models and children come together is in the area of education.

For better or for worse, the child is usually found in his (un)natural setting, the school. And in Western societies most children spend approximately 30 hours per week there and perhaps another 5-10 hours per week doing homework preparing themselves for their classroom lessons.

Now then, when we developmental psychologists finally spot the child in a niche in his usual habitat (a classroom in his school), and we want to test our models of how his mind works, we generally take him to what we like to call our laboratories (another room in the same school'). Generally what is tested is his understanding of peculiar tasks quite unlike those he has ever faced or will ever face unless, of course, another cognitive developmental psychologist happens to test him.

What seems strange in this tale is that there is often little resemblance between what it is that the child does cognitively in his classroom and what it is that he is asked to do cognitively in our "laboratories". One could easily draw the conclusion from this analysis that what is taught in schools ought to be changed and, in fact, that may not be far off the mark. But we'd like to draw another moral from this story: We ought to be in a position to say with some confidence that what goes on in children's thinking, learning, and development in our laboratories is the same as what goes on in children's thinking, learning, and development in the classroom. There is no in-principle reason why they should be different in these two places, and the fact that there is a deep feeling that a difference does exist is a sign that things are not right both in developmental psychology and in work being done in education that bears directly on developmental psychology.

We would like to present here a sketch of a model of how developmental psychology and science and mathematics education can be brought closer together. In fact, although one of us once described himself as an applied developmental psychologist where the area of application is education (Strauss, 1981), he now see the work we are about to describe as being educational-developmental psychology where the developmental and educational sides inform each other. In other words, the applied and basic parts of this kind of work blend so that those elements are essentially indistinguishable.

Stated somewhat differently, our remarks here can be best located within the framework of Vygotsky's (1966) work and this is principally because we see schooling as a means of passing on our cultural knowledge or as Vygotsky called it -- nonspontaneous concepts. Those are concepts that require tutoring and can be seen in contrast to the concepts that Piaget tested, which develop spontaneously, independent of tutoring. For an elaboration of this distinction, see Feldman (1980). Few people have attempted to understand how children represent nonspontaneous, school-learned knowledge, how it interacts with and informs their common sense, everyday, spontaneous understanding of the same concept, and how we engage both in the school setting.

It strikes us that this is one of the places where educational-developmental psychology theory and research ought to be done and if this were to take place, the line separating the developmental psychologists and the educational psychologists should get blurred. Rather than this being a negative point (one should generally advocate making clearer distinctions and not fuzzing them up), we see this as a positive step since it could bring academic developmental psychology into the domain of education without relinquishing its basic developmental concerns and it could make academic educational psychology more in touch with developmental issues and practice.

This is the direction of our work in theory and research. Essentially, we do not separate our developmental and educational psychology work since we view them as two sides of the same coin. Without a clear understanding of developmental landmarks of children's normative, common sense understanding of specific concepts (that are taught in school), we will not be in a position to insightfully determine the sequence and timing of instruction for the same concepts. Similarly, without a model of how development takes place, we will be hard-pressed to decide how to foster progressive developmental transitions, which is one of the goals of education. If one accepts these assumptions, then the question: Who does the work -- the developmental psychologist or the educational psychologist? is not a satisfactory way to formulate the division of labor.

The hybrid is an educational-developmental psychologist. Those who are this kind of hybrid and do research would probably be working at a middle level of theory where they keep an eye on and their work is informed by the larger issues of theory while what they are researching has meaning for educational theory and practice (Strauss, Globerson, & Mintz, in press).

The area of educational-developmental psychology we will use to make these ideas concrete is in curriculum development for the concepts of heat and temperature. Other cases where curriculum materials have been developed at Tel-Aviv University based on research in the development of the concepts to-be-taught in schools are: (1) the arithmetic average, where the developmental work was done by Sidney Strauss and Efraim Bichler and the curriculum development was done by Eebie Glaubman in consultation with Sidney Strauss, (2) probability, where the developmental work was done by Efraim Fishbein and the curriculum work was done by him and Avikam Goldbaum, and (3) chemical solutions, where the developmental work was done by Sidney Strauss, Ruth Stavy, and Nathan Orpaz and where the curriculum unit was developed by Ruth Stavy.

The work done on the development of the concepts of heat and temperature, which we shall now describe, was a joint effort by a team of investigators at Tel-Aviv University (see Strauss, Stavy, and Orpaz, 1977) and the curriculum materials were developed by Ruth Stavy, Varda Bar, and Baruch Berkowitz. We shall now point out four phases we have identified in curriculum development: (1) assessing the development of the concepts of interest for the curriculum unit, (2) developmental training for the difficult concepts, (3) the translation of the findings from the first and second phases into curriculum design, and (4) the evaluation of the curriculum unit's effectiveness.

The Development Of The Concepts Of Temperature and Heat

One way of characterizing the differences between temperature and heat is that the former is an intensive physical quantity while the latter is an extensive physical quantity (Carnap, 19[illegible]). An intensive physical quantity remains unchanged despite changes in its amount or extensive quantity. To illustrate, imagine that we have two containers of water each of which has same-temperature cold water. When we mix the water from the two containers the temperature will remain cold despite the change in the amount of water. In this example, temperature, being an intensive physical quantity, remained unchanged even though the water increased in its extensive quantity; i.e., its heat. Other examples of intensive physical quantities are sugar-water concentrations, viscosity, hardness, and density.

Those familiar with Piagetian tasks for measuring conservation of liquid quantity may recognize a similarity between the task just described and the conservation of continuous quantity task. In a typical conservation task two same-sized cups are filled with equal amounts of water and a child is asked to judge whether or not they are the same amount of water. The water from one of the

cups is then poured into a third, empty cup which is, say, taller and narrower than the original ones. The child is asked to compare the amount of water in the narrow cup, where the water level is higher, and the original cup which was left untouched. In the conservation task there is a change in the shape and location of the water but there is no change in its amount (extensive quantity). In contrast, in the intensive physical quantity task there is a change in the amount of water (extensive quantity), its shape, and its location, but not in the water's intensive quantity, that is, its temperature.

In a recent study Strauss, Stavy, & Orpaz (1977) investigated the development of children's reasoning about the concepts of heat and tumperature as they change and remain the same. Varying amounts of water were heated by equal or unequal numbers of candles in order to test children's developing understandings of ratio comparisons; e.g., the direct function, inverse function, and proportions. Also, varying amounts of water at the same or different temperatures were mixed, as in the example given above. A review of the findings on the development of children's understandings of these combinations are found in Strauss and Stavy (1982).

For the purposes of this paper, we will indicate the findings of how children at different ages understood the concept of intensive physical quantity; i.e., when same-temperature water was mixed. In one variant of the task we described above, two cups (A and B) with water that the experimenter called "cold water that is the same temperature" are poured into a third, empty cup (C) and the child is asked whether the water in cup C is the same temperature as the water was when it was in cups A and B. Very young children from approximately ages 4 to 5 or 6 often judge that the water was the same temperature "since they were the same temperature before and all you did was pour them together". Older children, from ages 5 through 8, produce incorrect judgments on the same task and judge that the water in cup C is twice as cold since "it has twice the amount of water". Still older children through age 12 produce correct judgments and justify them much like the very young children did. Data about children's correct judgments across ages are found in Table 1. The explanation we have offered for this finding (Strauss & Stavy, 1982) is that the very young children do not attend to the amounts of water (i.e., their extensive quantity), older children do attend to these amounts and judge temperature, an intensive physical quantity, as if it were an extensive physical quantity, while the oldest children separate intensive and extensive physical quantities and apply the respective nonadditivity and additivity appropriately.

This general phenomenon of an initially correct judgment is replaced by an incorrect judgment being replaced by a correct judgment once again has been termed U-shaped behavioral growth and has been documented in a number of cognitive domains (Strauss, 1982).

Insert Table 1 around here

Another way to represent this same concept of intensive physical quantity is via a numerical representation. For example, we can present children with water in two containers and measure their temperature with a thermometer. Let's say the temperature recorded in each cup was 10° C. The water is then poured into a third, empty cup and the children are asked to tell us the temperature of the mixed water. The overwhelming majority of children through age 13 answer that the mixed water's temperature was 20° C instead of the correct answer of 10° C (Strauss et al., 1977). Here it is clear that the children are adding numbers as if the addition models the joining of extensive physical quantities. We shall have more to say about this later.

This concludes our discussion of the first phase of curriculum development, i.e., gathering data about the developmental courses of the concepts that will appear in the curriculum unit of interest. These data are interesting in their own right since they inform important issues in developmental theory (see Strauss & Stavy, 1982). However, our educational purposes also commit us to gain some understanding of how progressive cognitive development occurs so that we can be informed about how to help children overcome conceptual difficulties they may be encountering. One way to accomplish this is through training studies that are conducted over a wide age range so as to pick up the developmental complexities in conceptual change.

Training

The purposes of the second, training, phase of curriculum development is to devise and test ways of helping children overcome the above-mentioned difficulties that were detected in the first phase. This is done with an eye towards incorporating these methods into the curriculum unit itself. As a consequence, this phase can be seen as both drawing on and informing conceptual and empirical work done in developmental psychology. Although there are many ways to carry out such work, I shall concentrate here on the method of inducing cognitive conflict as a means to accomplish the above.

In the case provided above, there was a conflict between children's qualitative, common sense understandings of temperature and their understanding of the number system as they apply it to temperature. Part of the conflict may be due to a confusion on the part of the children between joining and adding (Carnap, 1966; Cohen & Nagel, 1934; Hempel, 1952). Notice that in the case of intensivity tasks, water is being physically joined or combined. Hempel (1952) introduced a symbol for physical joining or combining, a small circle, instead of the plus sign. Hence, "o" designates, in our case, mixing water from one cup with water from another cup. In the case of extensive quantity, the arithmetic analogue is "+". The general principle of additivity, with respect to any magnitude, M, can be expressed:

$$M(A \circ B) = M(A) + M(B)$$

The reason for this distinction is that there are two types of additivity: (1) the physical operation of joining or mixing objects and (2) the arithmetic operation performed on numbers. One does not add, say, lengths or weights. Rather, one adds numbers that represent lengths of lines or weights of objects. Arithmetic operations of addition can be appropriately performed on numbers that represent measures of extensive physical quantities. In other words, arithmetic operations of addition model the physical joining of extensive physical quantities. It may be the case that children attempted to apply this model to numerical intensive physical quantity tasks, thus producing incorrect judgments on them. But, once again, we note that these very same children produced correct judgments when the same task was given but where the language used was qualitative.

In the study we will briefly report about, we measured the effects of conflict training between childen's qualitative and numerical representations of intensive physical quantity. The conflict, of course, was between the judgments produced by an individual child. This type of conflict, which has been sometimes been termed organizational disequilibrium conflict, has been shown to be effective in inducing cognitive change (Snyder & Feldman, 1977; Strauss & Ilan, 1974). For a review of conflict training techniques whose purposes were to induce progressive cognitive advance, see Strauss (1972). The main reason given for why this type of conflict has been effective is that the child himself offers contradictory judgments that result from thought organizations he has constructed. This is in contrast to the source of conflict coming from authorities (such as teachers and experimenters) who contradict what children are thinking.

Children from ages 7 to 11 were confronted with their own contradiction between their judgments on qualitative and numerical tasks and were asked what they thought about it. One sign, although not a decisive one, that children's qualitative and numerical representations of temperature are different was that many of the children at all ages found it difficult to understand that the qualitative and numerical versions were the same task asked in different ways. And this despite the fact that we used the same cups and water and even said things like, "Now let's take the same cold water and measure its temperature. Here we have cold water at 10°C and here we have water at 10°C."

After a discussion, children understood that the tasks were the same. We found three age-related responses to the conflict. The first type was found among the youngest children (the 7 and some 8-year-olds) who did not even recognize that a conflcit existed and argued that cold water when mixed with cold water remains cold and that the same same water when measured to be 10°C and mixed turns out to 20°C. Or as many children stated, "It's different when you have numbers".

The second type of response was found among somewhat older children (8 and 9-year-olds); their response was to change their correct qualitative judgment to an incorrect one by arguing that cold water when mixed with cold water at the same temperature becomes colder. This, of course, puts them in a double bind, since now they argue in the qualitative version that the mixed water is colder while the numerical equivalent leads to hotter water (20°C being hotter than 10°C). Here we see a drop in performance that results from one representational system which carries with it a set of rules (in this case additiuitiy of numbers being prominent) overriding another representational system whose code is

different; in this example, the experience-bound common sense notion of temperature as an intensive physical quantity.

The third response to the contradiction was found among the oldest children (many 10-year-olds) who changed their incorrect numerical answers to correct ones(10°C o 10°C = 10°C). This seems reasonable enough, but think for a moment about how this comes about. Why should children change their predispositions to add numbers? Why should they recognize that their arithmetic is modeling the wrong physical quantities? We have claimed elsewhere (Strauss & Stavy, 1982) that in the above case, a change in children's incorrect answers come about when they consult their correct qualitative understanding of the problem. That is, they must first pay attention to the fact that it is water that is being poured and temperature that is being asked about, and that temperature is not additive. This knowledge is necessary to change incorrect numerical solutions to correct ones. Now we see the interesting developmental phenomenon that the numerical representation that overrode the performance in the qualitative represenation (in the second response) becomes reorganized by that very qualitative representation.

There is also an interesting parallel in the history of science. It took 150 years from the time that Galileo invented the thermometer until the time that scientists could separate heat from temperature. The reason they were able to do so was that Black had developed a model that made that distinction. Out notice that this distinction was not made on the basis of the numerical data that were generated from using the thermometer; rather, the distinction was made when Black constructed a model of physical reality. For an interesting discussion of the history of the differentiation of heat and temperature, see Wiser & Carey (1983).

The above study tells us two things. First, it indicates that our technique was successful in inducing conceptual change and it could possibly serve as a model for other experiments involving conflicting qualitative and numerical representations. This point is important for decisions about sequencing within curriculum units. Second, we learned about how children at different ages and with different patterns of reasoning were affected by the training intervention. This point is important for the timing of experiences in curriculum development. In other words, we saw that most 10-year-old children resolved the conflict in a way that led to a correct understanding of both the qualitative and numerical aspects of the tasks. This is a clue for us that a curriculum unit, that attempted to include activities that would exploit the natural conflict between these two ways of representing the environment, should be introduced to classrooms where the children are at least 10-years-old. These two points lead us into the third phase of curriculum development: the design of the curriculum unit itself.

Curriculum Design

Here we have the problem of translating the research results into a curriculum unit. Before discussing how this has been done, We would like to note that a curriculum unit entitled "Temperature" was developed at Matal - The Tel-Aviv University Elementary School Science Project in 1974 by Ruth Stavy, Baruch Berkowitz, and Varda Bar. Underlying the unit was the notion that if children have experiences centering on the concept of temperature via verification procedures (such as measuring the temperatures of water with thermometers), improved understanding of the concepts will ensue. For example, if children using a thermometer measure the temperature of water in two containers to be 10° C and the water is then mixed into a third, empty container and it, too, is found to be 10° C, this verification of the intensive physical quantity should lead to a better understanding of the temperature concept. The actual result in the classroom was that many children thought the thermometer was broken since it was always "stuck at 10° C."

An informal assessment indicated that the children who were taught this unit did no better in solving these temperature tasks than children who received no formal instruction about this concept. In other words, instruction that involved both manipulating materials and assessing their effects was not effective in advancing these children's conceptualizations about temperature. We shall be arguing here that a curriculum unit that encourages children's activities and verification experiences, if not based on a thorough understanding of the developmental of children's competences about the concepts in question, is essentially blind and should not be expected to be successful as a teaching instrument.

Armed with this different way of thinking about curriculum development and given our research findings on the development of children's qualitative and numerical understandings of the temperature concept, Ruth Stavy, Varda Bar, and Baruch Berkowitz attempted to do what we claimed must be done in the third phase: i.e., translate the findings from research into a revised curriculum unit. A typical classroom in Israel has 35-40 children, so whatever unit is constructed must take into account the fact that it is unlikely that a teacher will have an opportunity, on an individual basis, to pose the problem of conflicting judgments. This means that the conflict should be provoked via questions raised in activities of the curriculum unit that lead children to confront their contradictions, in discussions between children or, preferably, both.

An example of how this was accomplished by Stavy, Berkowitz, and Bar is illustrated in Figure 1. What we see in this Figure are four pages of a worksheet booklet that was constructed by Jona Collman in such a way that page 1 could be folded back so that the qualitative scale would be aligned with the numerical scale on page 2. The example in the Figure is for the mixing of water at unequal temperatures; however, there were also other activities that involved mixing water whose initial temperatures were the same; i.e., intensive quantity tasks.

Insert Figure 1 around here

Notice in the Figure that the children were first requested to make a judgment about the temperature that results from mixing equal amounts of hot and cold water and were then requested to make a similar judgment about the mixing of water that was hot and measured to be 90° C and water that was cold and measured to be 10° C. This comes from the desire to get the qualitative and numerical representations engaged. Next they were asked if the two questions were the same or not. This was included to get the children to overcome the problem that we had found in our research, namely, many children did not even recognize that the qualitative and numerical tasks were the same except for the language being used to describe them. They were then asked to compare their answers by folding page 1 over onto page 2 and to note if there were discrepancies. This was done to indicate to the children the fact that their judgments differed when the tasks were presented qualitatively and numerically. The query about which is the correct answer is a way to have the conflict between judgments made obvious.

The above is an attempt to indicate how research findings from developmental psychology can inform curriculum design. The example given was one of several that attempted to induce cognitive conflict between children's qualitative and numerical representations of the results of mixing same-temperature and different-temperature water. However, it is not enough to note the close relation between results of developmental experiments and curriculum materials since even well-constructed curriculum materials pass the test of [illegible]ing to be well thought-out but are not successful in teaching the concepts of interest, as we saw in the first curriculum unit on "Temperature". This suggests that we need an evaluation of the results of having learned from the revised curriculum unit, the subject of the fourth phase of curriculum development.

Evaluation

The results of such an evaluation are found in detail in Stavy & Berkowitz (1980), so we will only sketch the study's design and main findings. A total of 77 children, all of whom were age 10, were given pretest items that included mixing equal and unequal amounts of the same and different-temperature water. This was designed to establish a baseline for placing the children into one of three groups: (1) those who were administered the revised curriculum unit under normal Israeli classroom conditions, (2) those who were given conflict training on an individual basis; i.e., the experimenter gave the conflict training to the individual child, and (3) those who were in a control group. All of the children were given a pretest and two posttests. The first posttest was given immediately after training (except for the control group that had no treatment) and the second posttest was given one month after the first posttest.

Insert Table 2 around here

Table 2 presents results of interest for our present purposes, which were that: (1) all of the children were statistically equivalent on their pretest understandings of the qualitative and numerical understandings of intensive physical quantities tasks and tasks measuring the results of mixing water at different temperatures (what we shall call intermediate temperature tasks), (2) the classroom-trained and individual instruction children who learned from the curriculum unit improved their understanding of the numerical aspect of both the intensive quantity and intermediate temperature tasks from the pretest to both posttests, and (3) the control group children did not improve significantly from the pretest to either of the posttests. In short, the findings were that the curriculum unit was effective in inducing progressive cognitive change.

To recapitulate, we have shown that curriculum development and developmental psychology can inform each other in such a way that both benefit. The first phase of curriculum development requires research into how the concepts of interest develop at a wide age range. The second phase requires training research at different ages so that we can detect how children over a wide age range resolve, in the case we presented, the cognitive conflicts that arose between two ways that they understand the temperature concept. The third phase involves translating the results of the first two phases into curriculum design. We showed how specific activities in the revised unit on "Temperature" included tasks that paralleled what we had learned from our initial developmental research. Notice that the sequence of activities and their timing were determined by that research. The fourth phase pertained to evaluating the effects of the curriculum unit on children's conceptual development when the unit was taught in a regular classroom. It should be noted that the tools for evaluating the cognitive achievements were developed in the first phase. Our results were that the curriculum based on these four phases was effective.

What all of this suggests is that it is possible to combine information about the developmental courses of various concepts and their interactions in making curricular decisions. With this information, our decisions will not be blind but rather focused and directed. It seems to us that a series of investigations might have to be conducted for each and every concept to be taught.

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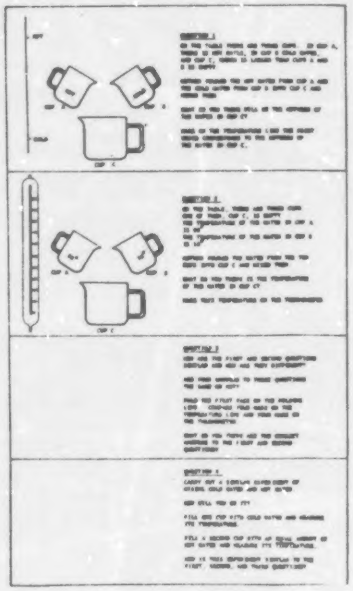
Figure 1: Example of a Revised Curriculum Unit Worksheet



Taken from Stavy & Berkowitz (1980)

Table 1

Percent Children

Correctly Solving Intensivity Tasks for Temperature

Age	Percent Correct
4	65
5	35
6	15
7	50
8	30
9	55
10	55
11	85
12	85
13	80

TABLE 2
Percent Children Successfully Solving Various Temperature Concepts

		INTENSIVITY		INTERMEDIATE TEMPERATURE	
GROUP	TEST	QUALITATIVE	QUANTITATIVE	QUALITATIVE	QUANTITATIVE
CLASSROOM	PRETEST	80.0	20.0	92.0	4.0
TRAINED	POSTTEST I	--	40.0	--	40.0
(N=25)	POSTTEST II	88.0	76.0	100.0	40.0
INDIVIDUALLY	PRETEST	76.9	26.9	100.0	3.5
TRAINED	POSTTEST I	--	61.5	--	26.9
(N=26)	POSTTEST II	88.4	80.7	100.0	30.7
CONTROL	PRETEST	80.7	30.6	92.3	3.8
(N=26)	POSTTEST I	--	30.7	--	11.6
	POSTTEST II	73.4	42.7	96.1	11.6

Taken from Stavy & Berkowitz (1980)

Misconceptions in Elementary Science - A Kellyian Perspective

Alan E. Wheeler, Brock University

Extract of an interview with Carl (age 10) dealing with a mechanical, wind-up beetle.

C: It's moving. Now the energy's just about stopped. He doesn't work any more.

I: What happened to the energy?

C: It wore down. It ran down.

I: And where did it go?

C: It went down in his legs to make it move. It used up all its energy in moving itself.

I: So where's the energy now?

C: It's gone.

I: Where did it go?

C: It went out of the white ... (reference to the white wind-up knob)

I: Whereabouts?

C: Maybe the energy just disappeared, once you've used it up it turns into air.

Introduction

The above extract of Carl's interview concerned his understanding of the word energy. His response was indicative of a number of students (age 9-12 years) interviewed. In the interviews an effort was made to use an approach that Kelly called, casting verbs 'in the invitational mood'. In his article entitled "The Language of Hypothesis" (1969) Kelly argued that this procedure invites the listener to cope with his circumstances (in this case objects associated with energy) in new ways and constructions and that:

> ... the language of hypothesis invites one to get on with the task of understanding life, to test, to calculate new experiences, and to profit from mistakes, rather than to be overwhelmed with guilt on realizing that he has made them. (p. 156)

The interview used in the present study was a modified form of the Interview-About-Instances approach (IAI) developed by Osborne and Gilbert (1980) and employed by Watts (1981) in his investigation on children's conception of force.

The major premise of the paper is that sound science teaching involves the identification, appreciation and understanding of the language, beliefs and expectations that students bring to bear on their science lessons (Driver and Easley, 1978). Carl's understanding, for example, of what actually happens during the transformation of mechanical energy in the wind-up toy into heat and frictional components reflects the traditional gap between what has been termed 'children's science' (Gilbert et al., 1981) and 'scientists' science', the Kuhnian term associated with the meaning held by the majority of the scientific community. Instead of viewing Carl's response as misconceiving or misunderstanding an energy change, it may be more accurate (from a psychological point of view) and useful (from an instructional point of view) to consider his response from a constructionist perspective. This exploratory paper analyzes students' conception of the term energy within George Kelly's Psychology of Personal Construct Theory (1955). The paper is divided into three major sections. The first provides an overview of Kelly's position and the application of his work with particular reference to science education. The second section focuses on energy as an important concept in the science curriculum and the method used here to unpack student constructions of the term. The concluding section of the paper presents a number of implications for science teaching within a Kellyian perspective, based on student interview data.

Constructive Alternatives

> Man looks at his world through transparent patterns or templets which he creates and then attempts to fit over the realities of which the world is composed.
>
> Kelly, 1955

In formulating his psychology of personal constructs, Kelly (1955, vols. 1, 2) was offering a constructive alternative to the behaviorist framework which was dominant in the 1950's. Kelly's work emphasizes the creative capacity of the living thing to represent the environment, not merely to respond to it. Each person is seen as actively constructing his world of events through a process of observation , interpretation, prediction and control.

Kelly's theory of personal constructs provides a rich conceptual framework for exploring students' understandings (sometimes referred to, erroneously I believe, as misconceptions) in many areas.

According to Kelly, the only way one grasps his environment is by means of interpretation through terms derived from past experiences. For Kelly a central feature of human functioning is the forming of an ever-shifting picture of reality. This set of personal constructs enables one to process information contained in new experiences and, in turn, formulate reaction to these experiences. A construct system thus represents a person's knowledge and views of the world. While the 'fit' of the construct system to reality is not always the best, one can improve his constructs by increasing his repertory, altering them to provide better fits, or by subsuming them with superordinate constructs or systems (Kelly, 1955, p. 9).

Kelly's central notion of 'man-the-scientist' may be a useful metaphor in attending to the apparent rift between 'children's science' and 'scientists' science'. He invites us to consider this view of person-as scientist:

> ... in examining man's undertakings, the questions he asks, the lines of inquiry he initiates, and the strategies he employs, rather than in analyzing the logical pattern and impact of the events with which he collides (p. 6.).

Regarding each 'person-as-a-scientist', whether the person is an elementary science student, a science teacher or a professional scientist, could serve as a productive model for research into alternative frameworks in science. Such a model would endorse the transitional nature of any change from the 'student-as-scientist', the focus of this paper, to the 'scientist-as-scientist' (i.e. scientists' science). All persons would presumably be found somewhere on this continuum which views 'person-as-scientist'. However, one's position on the scale would change over time, as constructions of reality are constantly tested out and modified to allow for better predictions (Pope, 1982).

The resilience of conceptions held by students in science is well known and has been well documented elsewhere (see, for example, Nussbaum and Novak, 1976; Clement, 1982; Lochhead, 1983). For Kelly this stability of alternative frameworks in the face of directed instruction designed to overcome such beliefs would not likely be surprising. He writes:

> Frequently his personal investment in the larger system or his personal dependence upon it, is so great that he will forego the adoption of a more precise construct in the substructure. *It may take a major set of psychotherapy or experience to get him to adjust his construction system to the point where the new and more precise construct can be incorporated* (Kelly, p. 9, emphasis added).

As Lochhead (1983) has reminded us, the Kellyian view of the learner as a constructivist is not a new one. He cites Rousseau's advice in *Emile*:

> Suggest problems but leave the solving of them to him. Whatever he knows, he should know not because you have told him, but because he has grasped it himself. Do not teach him science, let him discover it.

More recently, greater attention has been directed toward the implication of Kelly's work for education in general (see, for example, Pope and Keen, 1981; Bannister and Fransella, 1980) and instances where a Kellyian stance has been useful in uncovering reasons for decision-making in general (see, for example, Olson, 1982). Pope and Gilbert (1983) argue in their current work on personal experience and the construction of knowledge in science that Kelly's approach is particularly appropriate for science education in that his theory is grounded upon the base metaphor of 'man-the-scientist'.

We turn now to a consideration of the term 'energy' and a brief description of the method used to uncover students' construction of the term.

Energy

The concept of energy lies at the very core of much of science and construction of the term can be found at all levels of the science curriculum. Often the 'scientists' science' view of energy, i.e. the capacity of matter or radiation to perform physical work, bears little resemblance to intuitive notions of energy associated with everyday life. This may be related to Kelly's observation that the 'energy' construct has caused particular difficulty when used outside the physics domain. "It has never been possible to make a very literal translation of the concept of physical 'energy'".

Further he notes, "In its practical application to the realm of psychology mental 'energy' bears an uncomfortable resemblance to animism or even demonology" (p. 35).

In addition to a number of obvious concepts subsumed by the energy concept itself (i.e. force, work, mass, etc.) the complexity and abstraction of the term is further enhanced when one considers the expected understandings associated with a formal definition of energy. These would include at least the following: the understanding of the difference between potential and kinetic energy, the ability to identify a variety of forms of energy (mechanical, chemical, electrical, thermal, light, etc.) the convertibility of these forms, and the principle of universal conservation of energy. Also an additional emphasis in energy education often is an 'affective' component related to energy conservation and the wise use of energy resources. Viewed in this light, what understandings about energy might one expect from students (age 9-12 years)?

In the present exploratory investigation, constructions about 'energy' were elicited from a group of 18 students (age 9-12 years) using a modified form of the Interview-about-Instances technique (IAI) introduced by Gilbert and Osborne (1980). This approach is responsive to the views of the individual students themselves while incorporating

The power of a technique like the IAI is enhanced when viewed in conjunction with Kelly's techniques of psychotherapy. Salmon and Bannister (1974) have examined these therapeutic techniques and applied them to an educational context. They are presented here as a kind of typology that has heuristic value in formulating pedagogical techniques for student frameworks in mathematics and science.

Salmon and Bannister (1974) translated eight psychotherapy techniques from Kelly's work (pp. 32-34). They all involve the teacher (as therapist) devising instructional strategies when the student (as client) has:

1. things the 'wrong way round',
2. is using an inappropriate construct,
3. possesses a misleading unverbalized assumption,
4. believes ideas which are internally inconsistent,
5. failes to test constructs,
6. uses too limited or too broad interpretations,
7. needs constructs redefined, or
8. lacks necessary constructs.

The first technique concerns situations where the student has things 'the wrong way round' and the teacher suggests to the student that he should reverse his position with respect to one of the more obvious reference axes. An example drawn from arithmetic might be where the student has mastered the operations of multiplication and division, but confused the signs for these operations. Instructional procedures would then involve inducing him to reverse the position of the reference axis he is using.

a systematic attempt to explore individual construction. As mentioned earlier, the interviews used the technique Kelly called 'using the invitational mood'. This often took the form of asking the student to explain what energy is to a hypothetical friend. For example:

> Suppose a friend missed school when you talked about energy and came to you and asked, "What is energy?" What would you tell your friend?

The rest of the IAI approach as used here consisted of audio-recorded dyadic discussions with individual students, using a series of energy related objects. The objects were chosen to reflect various energy forms and served as a starting point to elicit a wide range of responses concerning energy. In each instance students were asked for explanations, other examples and their own meanings for terms. Whenever possible, the words used by the student in his or her construction were used by the interviewer to further explore the idea. Objects used included a wind-up mechanical beetle, a small 9 volt battery with wire and bulb, candle, sugar cube, steel balls on inclined plane, and wood samples. Students were encouraged to manipulate the objects during the sessions and explain their manipulations throughout the interviews.

Clearly the IAI method as a means of unpacking student frameworks about energy falls into that category Driver and Erickson (1983) have identified as 'problem-driven' research. That is, the central focus of the investigation is on practical implications designed to improve science instruction, rather than that type of research oriented towards theory-development. As such it can be viewed within the conceptual frame of 'case studies' where ample opportunity is afforded for discussions to develop in a relaxed, private atmosphere.

Of the remaining techniques the fourth and sixth were deemed evident in students' responses in the present investigation. The fourth type of problem concerns internal inconsistencies in the students' thinking.

S: (age 10) It's a sugar cube.

I: Do you think that's got any energy?

S: Mm, if I swallow it.

I: How does that work? When you swallow it?

S: It melts.

I: Does that give you energy?

S: No. Steaks give you energy.

I: Steaks? What about sugar, doesn't that have any energy?

S: No, just in ... in meat eh.

The educational goal here would be to elaborate on food in general as a source of energy and hence realize his conflicting interpretations. In a sense this type of problem may reflect the presence of a kind of decalage with respect to students 'conserving' energy concepts in a Piagetian use of the term.

Numerous instances of the sixth type of problem were encountered where students' interpretations were applied in too limited a way (e.g. are aware of several separate forms of energy but do not consider them as forms of a single phenomenon) or too broad a way (e.g. the student who views all energy as being 'electrical' in nature).

From a construct theory perspective, these eight situations described by Salmon and Bannister represent key junctures at which development may be blocked. As such they could be useful in both defining the type of student construction being dealt with and appropriate instructional strategies which are likely to bring about their solution. Teaching strategies such as those suggested by Posner et al. (1982) based on their work on bringing about conceptual change are seen as highly consistent with those that may arise logically out of techniques formulated by Kelly in his work in psychotherapy.

In closing, it should be noted that Kelly advocated the constant testing of his major hypothesis, which itself constitutes a human construct. His theory is always open to revision and possible replacement. I could not agree more with Pope (1982) who identified the challenge for educators is for them:

> ... to experiment with Kelly's notions as if they were useful ways of seeing and learning.

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STUDENTS' ALTERNATIVE CONCEPTIONS IN MECHANICS: A COHERENT SYSTEM OF PRECONCEPTIONS?

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PRECONCEPTIONS ABOUT FORCE AND MOTION

A number of researchers have reported findings that support the hypothesis that students hold beliefs similar to the impetus theories advocated by Medieval philosophers [1,2,3,4,5]. Clement [1] reported that many college engineering students make errors in solving the problems shown in Figs. 1, 2, and 3. In problems 1 and 2, for example, students drew forces in the direction of motion. These forces are ficticious from a Newtonian point of view. Furthermore, the error on the Rocket Problem shown in Fig. 3 can be accounted for by assuming that the students have the belief that "motion implies the existence of a force in the direction of the motion." Evidence for this belief also comes from analysis of interview transcripts. Thus there is a strong error pattern across these problems.

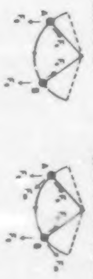
Table 1 shows data indicating that these errors are widespread and persistent. Many students still make the errors after taking one or even two semesters of

PENDULUM PROBLEM

Question: a) A pendulum is swinging from left to right as shown below. Draw arrows showing the direction of each force acting on the pendulum bob at point A. Do not show the total net force and do not include frictional forces. Label each arrow with a name that says what kind of force it is.

b) In a similar way, draw and label arrows showing the direction of each force acting on the pendulum bob when it reaches point B.

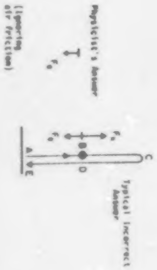
Physicist's Answer: Typical Incorrect Answer



Typical Incorrect Explanation: F_m is the force that makes the pendulum swing upward. If F_m weren't there, the pendulum could never move up to the top of its swing.

Figure 1

COIN PROBLEM



A coin is tossed from point A straight up into the air and caught at point E. On the dot to the left of the drawing draw one or more arrows showing the direction of each force acting on the coin when it is at point B. (Draw longer arrows for larger forces.)

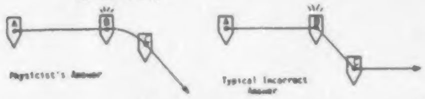
Typical Incorrect Answer: While the coin is on the way up, the "force from your hand", F_h, pushes up on the coin. On the way up it must be greater than F_g, otherwise the coin would be moving down.

Figure 2

ROCKET PROBLEM

a) A rocket is moving along sideways in deep space, with its engine off, from point A to point B. It is not near any planets or other outside forces. Its engine is fired at point B and left on for two seconds while the rocket travels from point B to some point C. Draw in the shape of the path from B to C. (Show your best guess for this problem even if you are unsure of the answer.)

b) Show the path from point C after the engine is turned off on the same drawing.



Typical Incorrect Answer: The force of the rocket engine combines with whatever was making it go from A to B to produce path BC. After C, whatever made it go from A to B will take over and make it go sideways again, causing the rocket to return to its original direction of motion.

Figure 3

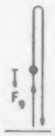
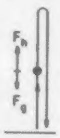
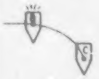
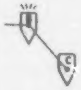
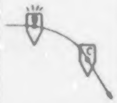
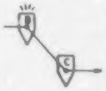
CORRECT ANSWER	TYPICAL WRONG ANSWER	% CORRECT BEFORE COURSE	% CORRECT AFTER COURSE	% CORRECT (for engineers with two semesters of Physics at a second institution)
		12% (n=34)	28% (n=43)	30% (n=37)
		.1% (n=150)	23% (n=43)	35% (n=37)
		38% (n=150)	72% (n=43)	65% (n=37)

Table 1

calculus-based physics. Percentages in the third column are from a sample of freshman engineering students before taking physics. For this group 90% of the incorrect answers to the Coin Problem and 74% of the incorrect answers to part B of the Rocket Problem were similar to the drawings shown in Table 1. Percentages in the fourth and fifth columns are from engineering majors who had completed a calculus-based course in mechanics. The results support the hypothesis that the "motion implies a force" preconception is not only widespread but is also highly resistant to change.

AN HISTORICAL COMPARISON

The following quotation is from a freshman student solving the Coin Problem. (I: indicates the interviewer and S: indicates the student.)

013 I: First of all, would there be any forces acting on it. And if so, what are they and what direction are they going and where do they come from?

014 S: At B there'd be two--that I could think of. The upward force--the upward original force that was given to the coin to make it fly in the air.

015 I: Uh-huh.

016 S: And there's always grav- the gravitational force which is working down on it. So in B there'd be these two opposite forces which is the original .. and the gravitational. But the reason that the coin is going up is because the original is greater than the gravitational.

I was surprised to find a very similar statement in Galileo's work:

> The body moves upward, provided the impressed motive force is greater than the resisting weight. But that force, as has been shown, is continuously weakened; it will finally become so diminished that it will no longer overcome the weight of the body and will not impel the body beyond that point...
>
> As the impressed force characteristically continues to decrease, the weight of the body begins to be predominant, and consequently the body begins to fall...
>
> This is what I consider to be the true cause of the acceleration of motion [6].

It is remarkable how similar the statements are, given that the speakers are separated culturally by over 300 years. In each case, they describe a continuing upward force acting on the coin as a cause of motion, and state that the upward motion requires that this force be larger than the force of gravity.

When he published Two New Sciences much later in his career, Galileo presented essentially the above argument, but was unwilling to endorse or refute it [7]. He assigned the argument to Sagredo, the "middleman" in the dialogs, rather than to either Salviati, the spokesman representing himself, or to Simplicio, whose views are closest to Galileo's Aristotelian adversaries.

But the quotation from Galileo above indicates that real conceptual change in this area is an extremely difficult task that should not be underestimated. The fact that Galileo propounded a careful and well-articulated impetus theory during part of his career, and the fact that present-day students give explanations that are very similar in their basic aspects to that theory, is supporting evidence for the strong, intuitive attraction of the "motion implies force" belief. The students' errors appear not to be simply capricious; the belief appears to be a plausible one that has been constructed by students on the basis of experience. To me, the most important implication of this historical parallel is that it indicates that there has been an impressive spontaneous learning mechanism at work in the students. The impetus belief is not taught formally in schools. But some learning mechanism has led to the formation of these intuitions in daily life. The intuitions form a belief that is impressively similar to one propounded by Galileo.

A COHERENT SYSTEM OF PRECONCEPTIONS?

Now I would like to shift to a more speculative mode in order to talk about the larger context in which the "motion implies a force" misconception can occur. My belief is that there is typically a whole system of conceptions surrounding an impetus-like belief in the beginning physics student. A partial outline of such a system is shown in Fig. 4. This view is conjectural and must be viewed as incomplete and in need of evaluation, but it may be of some use as an heuristic for stimulating research.

The "motion implies a force" belief is represented in conception 1 of Fig. 4 as the impetus belief that there is a force inside a moving object that keeps it going and causes it to have some speed. The diagram also indicates that the force can fade away as the object moves along. But the impetus conception does not act alone. It operates in cooperation with other conceptions. We have observed evidence for these beliefs in taped tutoring sessions and clinical interviews, but larger data collection studies are needed. Conception 2 on the left hand side of Fig. 4 shows the belief that contact forces come only from active sources of power. For example, friction is not a force for most naive students, because you cannot see where it is coming from: there is nothing moving to produce it. Instead, friction is seen as a directionless "resistance" to movement. Similarly, a table cannot produce a normal force upward on an object resting on it, because the table is not seen as an active source of power [8]. Rather, students may view the table as a "barrier", as indicated in conception 3.

Conception 4 in the diagram indicates that some students believe that a stronger force will completely dominate a weaker force: if I push on an object both from the right and from the back and the force from the back is stronger, then the object may simply move forward. In real life if a large man is struggling with a small man, where the large man wants to go north and the small man wants to go east, they may very well go north. That strong forces can dominate weak forces is, from this point of view, a plausible non-Newtonian belief.

Conception 5 indicates that rest is perceived as fundamentally different from motion. This may be a fundamental perceptual distinction that is "hard-wired" to some extent. It lends support to the impetus theory, which

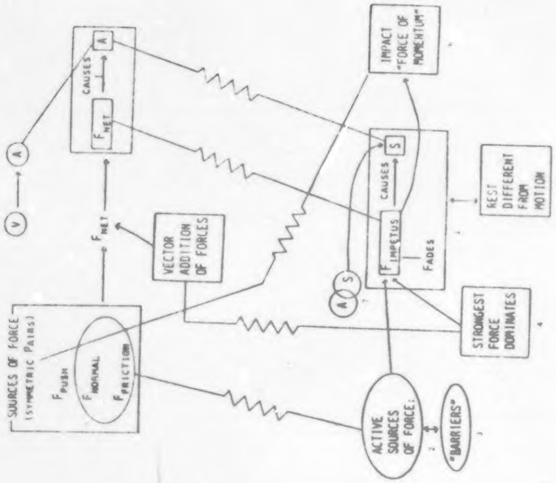
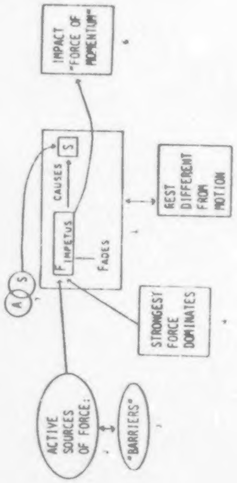

IMPACT "FORCE OF MOMENTUM"
CAUSES
A
F_{NET}
V
A
F_{NET}
VECTOR ADDITION OF FORCES
S
CAUSES
$F_{IMPETUS}$
FADES
REST DIFFERENT FROM MOTION
A S
SOURCES OF FORCE (SYMMETRIC PAIRS)
F_{PUSH}
F_{NORMAL}
$F_{FRICTION}$
STRONGEST FORCE DOMINATES
ACTIVE SOURCES OF FORCE:
"BARRIERS"

Figure 5


IMPACT "FORCE OF MOMENTUM"
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CAUSES
$F_{IMPETUS}$
FADES
REST DIFFERENT FROM MOTION
A S
STRONGEST FORCE DOMINATES
ACTIVE SOURCES OF FORCE:
"BARRIERS"

Figure 4

also makes a fundamental distinction between motion and rest [5] (a Newtonian view does not). Impetus forces are assigned only to moving objects, whereas in Newtonian physics, rest is seen as one point on a continuum of possible positive or negative motion in a particular frame of reference.

Conception 6 refers to the impact "force of momentum". For example, a student may say that when you catch a baseball in your bare hand you can "feel" the impetus force coming out into your hand. This supports the idea that there is a force in the object as it comes toward your hand. Thus there are beliefs involving impetus which explain collision events as well as trajectories. Conception 7 indicates that for the student there is no concept of acceleration or that it has been confounded with the concept of speed [12]. This makes it impossible for the student to conceive of force being connected to acceleration.

My belief is that these ideas work together to sabotage attempts to teach the standard Newtonian views shown in Fig. 5. In the standard Newtonian view one has certain sources of force, some of which are shown here, that produce a net force on a body via the vector addition of forces. The net force then causes an acceleration of the body. Fig. 5 shows how the student's system of beliefs can be in disequilibrium with the Newtonian system. For example, if the student studying forces of friction and normal forces believes that contact forces can only come from something active or capable of moving, then one will most likely have a disequilibrium situation. Furthermore, if the student tends to treat only the moving object as a source of force in a collision with a stationary object, this belief conflicts with the Newtonian view of symmetrical force pairs. Similarly, there are conflicts between the way forces are addded and between the effects of that force on the way motion is caused or changed.

If this view is correct then, there is a "cognitive conspiracy" here against what the physics teacher is trying to do. The system of preconceptions is interconnected and coherent enough to make it quite stable and therefore resistant to change. It acts like a world view or paradigm in the sense of Kuhn [9] which resists change. This view may provide an explanation for why students have so much difficulty with the problems discussed earlier, even after they have taken calculus-based physics courses. The diagram in Fig. 5, however, must be seen as a first-order model. Questions need to be asked, for example, about the extent to which the underlying concepts of force and speed themselves are equivalent for the student to the established concepts used in physics. How these conceptions relate to other conceptions in mechanics is also an open question.

IMPLICATIONS FOR INSTRUCTION

As evidenced by the similarity to ideas voiced by Galileo, the "motion implies a force" belief is an impressive construction on the part of the student. It would be interesting if there were some way to tap into the students' learning processes which accomplish this construction. One would like to use those same processes to help the student go beyond this system toward an even more powerful explanatory system.

Some suggestions have begun to appear in the literature for how to take preconceptions into account during instruction including: getting students to articulate preconceptions so that they can be discussed; arranging laboratory experiences which conflict with preconceptions; and asking students to translate between systems of representation such as graphs, tables, equations, and verbal descriptons to describe phenomena in a consistent manner.

To these I would add the need for developing key metaphors which marshall intuitions the student already has, in order to give students concrete physical models at an intuitive level. In this approach, in order to explain the deceleration of an object experiencing friction, the student must learn to reject or supress the "impetus force dying away" model and learn to use a metaphor like viewing the situation as an external frictional force which "whittles away at the velocity". A collection of such metaphors might be a strong intuitive base for supporting a more formal mathematical theory of mechanics [10,11]. My suspicion is that the coherence and persistence of the preconceptual system in this area means that a number of innovative teaching techniques will need to be combined in order to foster meaningful learning of the Newtonian system on the part of most students.

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ENERGY CONCEPTIONS HELD BY STUDENTS AND CONSEQUENCES FOR SCIENCE TEACHING

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INTRODUCTION

Energy education has become an area of major interest within school curriculum. School teaching is expected to equip students with sufficient knowledge, skills and abilities to be able to live in a world which is faced with rising energy demands and shrinking energy resources. Science instruction, especially physics instruction, plays an important role in this integrated effort. The physical concept of energy is seen as a basis for the mentioned understanding of energy supply. There are several problems connected with this. On the one hand, it is often overlooked that the energy concept used in discussions about energy supply is not necessarily the energy concept used in science. On the other hand, it must be investigated whether those aspects of the physical energy concept which may contribute to an understanding of energy supply can be grasped by the students.

I would like to give an overview of studies on learning energy which have been carried out at the IPN in Kiel. My main concern will be energy conceptions held by students before and after physics instruction, as well as their consequences for science teaching.

THE FORMATION OF ENERGY IDEAS DURING COGNITIVE DEVELOPMENT

In the study I want to mention first, Ch. Jenelten-Allkofer has investigated whether certain roots of the energy concept form during cognitive development (see Jenelten-Allkofer,1979; Jenelten-Allkofer, Duit, 1980). Within the framework of Piagetian research she interviewed 45 children, 5 to 15 years old. "Critical interviews" (in the style of Jean Piaget and his co-workers) dealt with the three experiments in fig.1. The experiments were meant to reveal different aspects of energy ideas. The first one (a) is frequently used in physics teaching to demonstrate the conversion of the tension energy of the spring into the motion energy of the ball. We wanted to know whether children attach "something" to the stretched spring or to the moving ball which can be interpreted as the beginning of an energy conceptualisation. Of course, we did not expect the word energy to be used by the children. We have accepted wordslike swing, force, pressure and motion as indicator for such a conceptualisation. The experiment (a) was also used to provide hints as to whether a certain "something" passes from the spring to the ball.

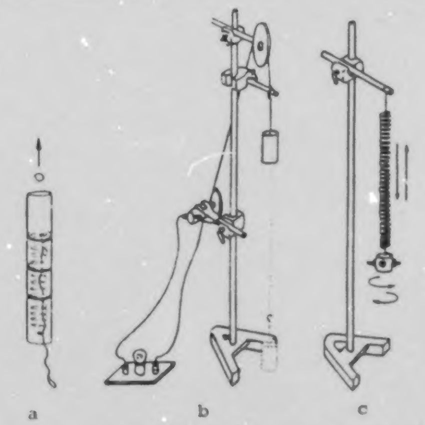

fig. 1: Experiments used by Jenelten-Allkofer (1979)

The second experiment (b) contains a chain of events which has more than two stations. We wanted to move the children to voice their ideas on energy transfers and conversions.
The third experiment (c) depicts the conversion of the linear

oscillation of the spring to the oscillation of the rotating body which hangs from the spring. There is a permanent exchange between the two kinds of oscillations. We wanted to stimulate ideas of the interplay between conversion and conservation.

The aims of the study were twofold. On the one hand, the theory of Piaget and his co-workers concerning ideas of causality were to be verified by means of another example. On the other hand, the mentioned formation of energy ideas was to be investigated.

When planning instruction about energy it is important to note that young children have severe difficulties observing the processes correctly. In experiment (b), for instance, several young children were not able to see the coincidence of the falling ball and the glowing bulb. Not before the age of about 10 to 12 were most of the students able to observe and describe the chain of events correctly. Even more difficulties became evident in experiment (c). Young children mentioned almost no connection between the two oscillations. Many children between the ages 8 to 12 were not able to observe the compensation of the two variables correctly. They were of the opinion that the amplitude of the spring's oscillations increases when the amplitude of the body's rotation increases. Only older children gave a correct description.

Where notions of energy are concerned, quite early in cognitive development a notion seems to be formed of something which is attached to the stretched spring or the moving ball. This notions is similar to the potency notion of force that Piaget (1973) describes.

Most children of about 10 to 12 years seem to have the notion of a somewhat abstract something which flows in processes from one place to the other. These findings are in accordance with others from Piagetian research (see e.g. Piaget, de Lannoy, 1973).

The findings seem to allow the following interpretation.

During cognitive development a notion is formed which may be taken as the root of the energy transfer and conversion ideas. Among most students between the ages of 10 and 12 we found the idea of a something which is transported and converted during processes. An idea of energy conservation was evident only among some older children which had already heard about energy and energy conservation in school.

The most important consequences of the mentioned findings for energy teaching seem to be the following. Aspects of energy transfer and energy conversion may be introduced comparatively early (say in grade 5 or 6). They can be based on roots already existing within the thinking of most students of this age level. Exactly these aspects seem to cause only a few problems to students in energy courses. Results from a study on learning energy at the primary level, accomplished here in Ithaca (see McClelland, 1970) as well as other studies (see Dahncke, Duit, Niedderer, 1973; Jung et al. 1977), may be taken as a reference. The teaching of energy conservation will meet probably more difficulties. Indeed, results of studies discussed later in this paper reveal severe difficulties in this field.

STUDENTS' NOTIONS ABOUT THE ENERGY CONCEPT - BEFORE AND AFTER PHYSICS INSTRUCTION

Studies on learning the energy concept during an instruction unit on energy and during physics instruction in grades 7 to 10 will be summarized here. Students in Kiel (W-Germany) took part in those studies and so did students in Manila (the Philippines). Students in Basel (Switzerland) served as "control samples" because these grade 7 and grade 10 students had no physics instruction at all.

In the following some findings mainly from students in Kiel are presented. Findings from Manila will not be reported here[1]

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[1] Comprehensive overviews of the studies are given by Duit (1982, 1983a). Results from Manila are reported by Duit, Talisayon (1981).

Methods used in the studies

An overview of the questionnaire used in the studies before and after physics instruction is given in fig. 2. The first part focusses on the meaning of the words (the concepts' names) energy, work, power and force. This part is discussed in some detail in another paper of this conference (see Duit, 1983b). The second part contains three simple problems of mechanics. The students are asked to make predictions and to give explanations for the predictions. This part is meant to investigate whether the students make use of the energy concept (and especially of the principle of energy conservation) in their explanations or whether they use words from everyday language and everyday conceptions. Two of these tasks are presented in fig. 5.

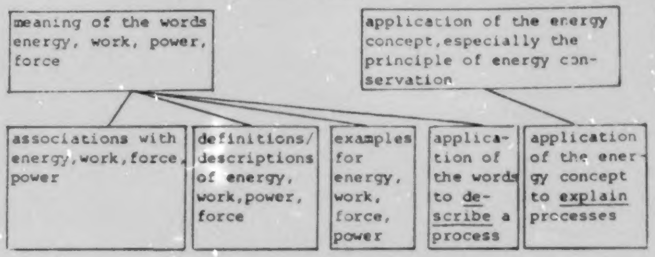

meaning of the words energy, work, power, force
application of the energy concept, especially the principle of energy conservation
associations with energy, work, force, power
definitions/ descriptions of energy, work, power, force
examples for energy, work, force, power
application of the words to describe a process
application of the energy concept to explain processes

fig. 2: Overview of the questionnaire

In one of the studies on learning the energy concept during an instruction unit, interviews were also employed. About 20 students were presented with the answers they gave in the questionnaire and were asked for further explanations. The same students were interviewed before and after the instruction unit in order to obtain information on changes of notions due to instruction.

I would like, by the way, to mention that my experiences with such a combination of questionnaire and interview are encouraging. The interview increases the insight gained by the questionnaire substantially.

The meaning of energy in German everyday language

Findings from part 1 of the questionnaire which are presented in another paper at this conference (Duit, 1983b) may be summarized as follows.

In German everyday language - for the overwhelming majority of students - energy has the meaning of a general kind of fuel. Energy can be obtained from certain sources (e.g. fuels like oil, gasoline, coal or sun, wind, moving water). Energy and current (electricity) are closely linked; electric current (electricity) is seen as an important energy provider. Relations between energy and phenomena such as heat, light and motion also fit into the framework of the general fuel idea. They provide energy, on the one hand, and they result from energy on the other.

The general fuel energy can be used in manifold areas but the use in technical areas predominates. Only a small number of students is aware that food is among the most important energy sources. Quite often, energy is taken as a luxury item. It is regarded not as a basic precondition of processes in general but something that makes our lives more comfortable.

My findings reflect the use of the word energy in the public discussion of energy supply. It is interesting that the "vitalistic" meaning of energy (which may be characterized by words like endeavour or vigor) is concealed nearly totally by the meaning outlined above. It may be that the methods employed in my studies especially stimulate the mentioned notion of a general fuel (Solomon, 1981, has found the vitalistic notion among students and adults). Whatever the reasons may be my findings point out that even younger students associate a variety of ideas with energy. Seen from the use of the word energy in the public discussion of energy problems in society most of these ideas are quite meaningful. Most of these ideas may be taken as a basis for learning energy in school. This is true, for instance, for the idea that energy is needed to run processes and that energy is a something (general fuel) which can be transported and changed (converted). Other ideas, of course, have to be revised or changed totally (e.g. energy consumption).

Energy and work

In many physics courses in school, energy is still introduced via work. There is much to be said against this approach. For instance, energy is restricted mainly to mechanics. The associations with energy (fig. 3) and work (fig. 4) as well as other findings of my studies point out the following differences. Whereas Energy is predominantly seen as a general kind of fuel, work is associated mainly with activities (both mental and physical) in manifold fields (e.g. school, working, world, society, households, sports). Quite often there is evidence of an "emotional loading": work is something one does not like to do.

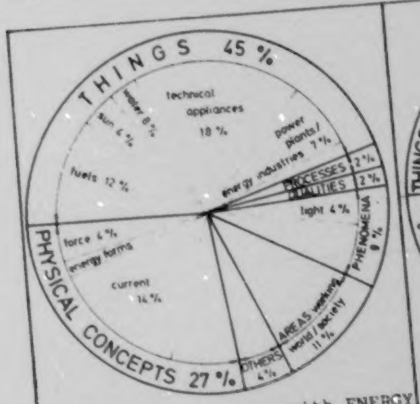


fig. 3: Associations with ENERGY

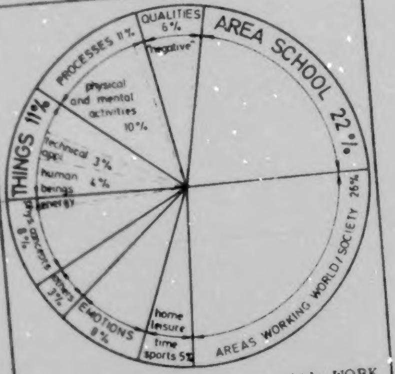


fig. 4: Associations with WORK

147 students / grade 6/ before physics instruction

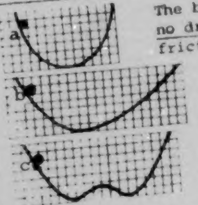
If energy is conceptualized as ability to do work (or the like), misunderstandings are unavoidable. Such an energy concept obviously does not fit into the everyday conception of energy held by most of the students. Therefore, the concept of work does not pave the way to the energy concept. I think, this path is a needless detour or even a dead end street for many students.

Change of energy conceptions during instruction

Results presented in another paper at this conference (Duit, 1983b) point out that the above mentioned energy conception is not basically changed during physics instruction. When associations with energy before and after physics instruction are concerned, for instance, there is only a greater fraction of energy forms and other connections with energy among students after physics instruction. Of course, there are further impacts of energy teaching but they seem to be rather limited. Aspects of the energy concept which had been given considerable attention during instruction (e.g. the principle of energy conservation) were mentioned only by a small minority of students.

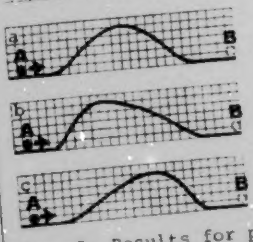
Application of the energy concept

In part two of my questionnaire the students were asked to explain some processes used in physics instruction to convince the students that the principle of energy conservation is valid. Fig. 5 presents results for two tasks.



The ball is released at the marked spot and rolls with no drive of it's own. We will pretend that there is no friction.

	a	b	c
Prediction of correct height	47	26	33
Use of energy for explanation	35	26	22
Use of energy conservation for explanation	26	18	15



The ball is passing spot A with a speed being great enough to go over the slopes. We will pretend that there is no friction.

	a	b	c
Prediction of correct speed at spot B	75	35	31
Use of energy for explanation	22	18	17
Use of energy conservation for explanation	16	9	9

fig. 5: Results for problems on the frictionless motion of a ball. Figures give percentages. 171 students/grade 10/ after physics instruction in grades 7 to 10. The idea of these tasks stems from Dahncke, 1973.

Of course, the processes of these tasks have not been discussed in physics instruction.

The number of students who predict the correct heights or speeds of the ball on paths b and c is substantially smaller than on paths a. The word "energy" is used only by a minority of students when explaining the predictions. Most students use words from their everyday language like swing. A rather small number of students argues using the principle of energy conservation. Most explanations follow notions and ideas stemming from everyday experiences or mention geometrical qualities of the paths (e.g. the symmetry of paths a or the different steepness of the right and left side of paths b).

The findings presented in fig. 5 as well as other findings from my studies point out that most of the students do not make use of the energy concept taught in physics instruction when dealing with simple processes of mechanics. Some students still argue using energy conservation in simple cases (e.g. the symmetrical paths a in fig. 5). But many of them fall back to everyday conceptions as soon as it becomes a little bit more complicated. Sometimes an interesting mixup of physical notions and everyday notions is evident[1] from interviews. There are some students who predict that the ball will reach spot (1) when released at spot (b) but that the ball will go back to spot (b) (see fig. 6). One student explains this prediction with energy conservation. He is of the opinion that the energy of the ball is dependent on the length of the path and not on the gained height. He was already of the opinion before physics instruction that the length of the path plays an important role.

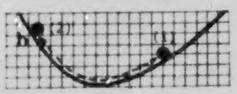


fig. 6

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[1] Gilbert, Watts, Osborne (1982) describe other examples for this.

Summary

It was only possible to present some findings of my studies here. The main results are valid for learning of energy during an instruction unit in grade 8 as well as for learning of energy during physics instruction at grades 7 to 10. Of course, the results may not be generalized for energy teaching in general. The number of students is limited (about 400 students enrolled in studies on learning during an instruction unit; about 140 grade 6 students and 170 grade 10 students in the other study). Furthermore, teaching energy was similar in all studies. It followed mainly traditional paths. The concept of work, for instance, played an important role.

APPLICATION OF THE ENERGY CONCEPT OUTSIDE OF PHYSICS INSTRUCTION

The studies on learning the energy concept discussed above reveal severe difficulties on the part of students to apply the energy concept when dealing with physics problems in the physics classroom. If it is an aim of energy teaching to provide students with knowledge to understand problems of energy supply, application of the physical energy concept outside physics classrooms is expected. The small study described here tried to get some information about such application.

About one year after students had learned about energy in physics instruction they were asked by the German teacher to write an essay on "Much is to be heard about energy these days. Please explain what energy is and please explain the importance of energy for us" (see Duit, Zelewski, 1979). The students did not know that the physics teacher (and me) initiated the essay. Although the physics teacher had the impression that the students had learned and remembered the energy stuff quite well, most students did not make use of any knowledge stemming from physics instruction. Some students who tried to employ such knowledge failed. Only a very small number of students were able to apply some aspects of the physical energy concept when explaining the importance of energy supply.

In most of the essays physical aspects (e.g. energy conservation and energy conversion) were covered by notions predominant in mass media (e.g. consumption of energy). In general, most knowledge on energy use presented in the essays stemed from mass media.

It has to be pointed out that essays are avaible only from two classes (grade 8) of about 35 students each. Therefore, only results from "case studies" have been presented. Furthermore, the results do not offer information whether the students are able to make use of the physical energy concept as a matter of principle: They merely indicate that these students have not done it while writing an essay in German instruction. Notwithstanding this, the results are in accordance with complaints of other authors that students do not use the energy concept when dealing with problems of the real world although many of them are able to say what energy is (see Wehner, 1972; Black, 1981; Gubanski, 1981).

SOME CONCLUSIONS FOR SCIENCE INSTRUCTION AND FOR RESEARCH IN THE AREA OF STUDENTS' NOTIONS

One of the most important limitations of learning energy in physics instruction is the inability of the majority of students to make use of the energy concept. It seems that physics instruction is not able to instill faith in the use of this concept. This is already true for applications to problems posed in physics instruction. The results of the presented studies point out that application of the energy concept learned in science instruction in the area of energy problems of society seems to be unlikely for many students.
I think that energy education cannot take it for granted that physics instruction offers a sufficient basis for understanding the problems of energy supply.

The problems concerning the learning of the energy concept seem to be valid not only for this concept but for learning a

great deal of science knowledge as well. Many studies dealing with students' notions (alternative frameworks, misconceptions and the like) point out that science instruction very often is not able to shake everyday notions (i.e. notions gained during everyday experiences) basicly. Students make use of science knowledge in simple cases but as soon as it becomes a little more complicated they don't have confidence in physical knowledge but trust in everyday knowledge. They employ everyday notions instead of physical principles and they use words from everyday language instead of the technical terms from science. It seems as if science instruction is able only to instill a thin layer. Under the thin science layer everyday knowledge is still alive.

To overcome the mentioned difficulties is one of the most important challenges for science instruction research and curriculum development. But it is necessary to appraise the outlined difficulties correctly. I think the following aspect is of importance in this respect.
Learning science knowledge is always a long-term endeavor. It is not possible to learn such broad concepts like energy in one single attempt. It seemsto be unlikely that we can shake notions gained through everyday experiences over many years in a few lessons.
I think we need patience. We should be pleased with little impacts of our teaching efforts. Progress is walking slowly step by step.

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Advanced Physics Courses Do Not Provide Students With Conceptual Change

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Ecole Polytechnique

INTRODUCTION

Students can pass through introductory physics courses without developing a conceptual knowledge of physics. This is known, though not sufficiently emphasized in physics departments. Pedagogical research has pointed out factors explaining the students' behaviour. First, their minds are not virgin when they arrive in the classroom, but filled with naive conceptions which, according to Champagne (1983) and Osborne (1983), are amazingly persistent and resistant to change. Secondly, Lin (1982) has well described the dichotomy between learning physics and passing courses. Due to time pressure and deficient problem-solving abilities, the students focus their attention on the explicit curriculum rather than on the implicit one. Finally, Clement (1981) and Faucher (1981) have shown the limitations of solving problems only with formulas, the underlying conceptual basis being then not perceived.

Facing this situation in introductory courses, physics teachers assume that conceptual development will occur later in the curriculum. Being more mature, the students would acquire it in the advanced courses. We have developed a test to verify this assumption. We present this test, the results which are rather disappointing and some implications for physics instruction.

CON-PHY-TEST

CON-PHY-TEST has been developed to evaluate at what level basic concepts of mechanics and electricity and magnetism are grasped by students. Its consists of 20 qualitative questions which require almost no calculations. The test must be answered in 45 minutes. The students are requested to be brief, but to explain their answers. All the questions have the same weight.

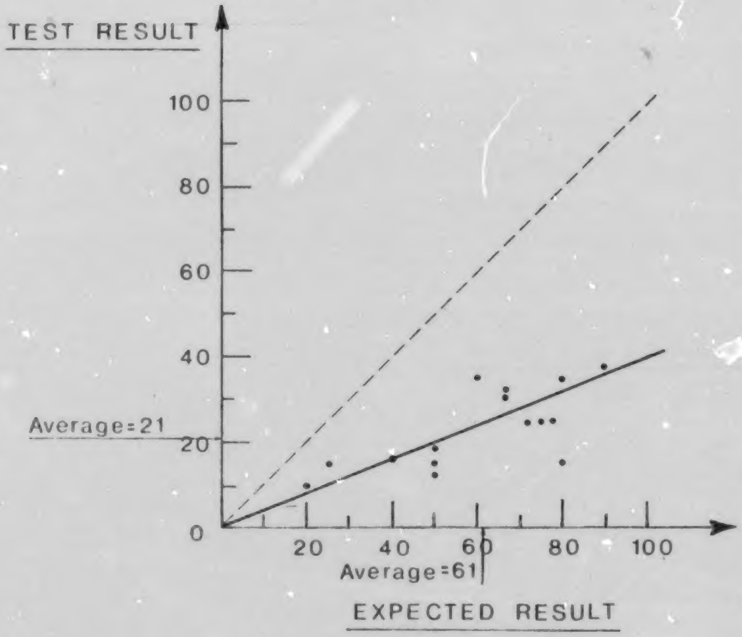
It has been administered to sophmore and senior engineering students. Mechanics and electromagnetism have been chosen, because all sophmore students had attended a course in these subjects in the previous year. The questions have been built so that they relate to material which had been touched in class directly or indirectly. At the end, the students were asked to comment on the nature of the questions and to predict their own result and the group average.

THE RESULTS

28 sophmore engineering physics students (the whole class) passed the test. The average was 21%, with a maximum of 39% and a minimum of 9%. The expected class average was 61%, indicating that the sophmore students perceived themselves as "good in physics" and unaware of their weakness in qualitative physics as revealed by their 21% average. The students had a tendancy to evaluate themselves in comparison with their previous physics results (A students being the highest, etc...). At the end of the test, they did not seem to understand that success in the exams does not imply a good comprehension of the concepts. The graph shows how the results obtained at the test differ from the predictions.

8 senior engineering physics students (half of the class) volunteered to pass the test. Their average was 30%, slightly higher than that of the sophmore students. The minimum result was 23% and the maximum 42%. The difference is not very large; it can be inferred that it is negligible, if we assume

that only the senior students really interested in the test passed it, thereby raising the average. The senior students were more realistic in their own expectations and in their expected group average of 53%. *Does modesty grows with maturity?*



The comments of the sophmore group were divergent. Half of them found the questions interesting and challenging; if more of the same type had been incorporated in the exams, they think they would have obtained a better result. The other half judged the questions vague, confusing and not very attractive for engineering students who like numerical answers. The senior group was more uniformly favorable to the qualitative nature of the questions.

ANALYSIS

It is not our aim to analyze the various misconceptions found in the answers like others (Schuster 1981; Trowbridge 1980, 1981; Viennot 1979) have done it for other tests. This would necessitate interviews and a larger sample of students. Our main concern is the comparison between sophomore and senior students. The results show that these two groups have about the same conceptual knowledge of physics. The senior group did not seem to benefit by two extra years of lectures to deepen their understanding of physics. Of course, the lectures during these two years were not all devoted to physics, but also to mathematics, humanities, or engineering.

There are two reasons why students seem to reach an asymptotic conceptual level. The first is that, in introductory courses, the qualitative aspects of physics are not touched upon and too much emphasis in given to solving numerical problems. The second edition (1981) of the well-known text "Fundamentals of Physics" by Halliday and Resnick contains in its 816 pages

844 questions (or "thought problems")

256 solved examples

1872 problems

These authors have made a pedagogical breakthrough by incorporating so many qualitative questions. Unfortunately, too many teachers adopt this book they consider the best without even being aware of one of its strong points.

The second reason is that intermediate and advanced courses assume that the concepts have been well grasped in the introductory courses. Therefore, no review is made, no reinforcement is planned. Students are assumed to have reached the level of experts.

IMPLICATIONS

The implications for teaching are evident if one wants to draw more attention to the conceptual aspects of physics. In introductory courses, more time should be devoted to qualitative questions. An important fraction of the exam and assignment problems should deal with concepts. One should not leave aside numerical problems but they should be de-emphasized. Students should be advised to explain the physical phenomena in their own words and not to rely on rote memorization. Students believe in grades, so let use grades to stress the importance of concepts.

Advanced courses should begin by a review of the basic concepts (not only the formulas, but the meaning of the concepts). During the term, the elaboration of new material should include flashbacks to these basic concepts and to new concepts.

Consider the question No 13 of the test: "*An electromagnetic wave is propagating in a medium. Does Faraday's law apply to the wave?*" Many students answered that Faraday's law applies to fields, not to waves. Though they had solved complicated problems in two advanced electromagnetism courses, they did not catch the concept of electromagnetic wave. In these two courses, the synthesis between mathematical procedures and basic physics was definitely absent.

The conceptual flaws of junior and senior students should be paid more attention to by all their teachers who should be aware of their existence. It should be publicized that, in answering question No 7, some seniors said that "the earth attracts the moon with a greater force than the moon attracts the earth". These seniors, which show an average academic record, must have well solved numerical problems on Newton's third law.

The performance of engineering physics students in standard, quantitative physics exams is better than that of non-physics majors. What can we conclude of the conceptual physics level of senior civil or industrial engineering students? Would there be an important difference in the test results if they had passed the test?

The two senior students who had the lowest score had been tutors for two years in our PSI mechanics course. It is feared that, while they were helpful to students for solving problems or explaining some theoretical points, they could not give insights in qualitative questions. When hiring tutors, one should consider their conceptual development.

CONCLUSION

Though concepts are not sufficiently grasped in introductory physics courses, teachers assume that advanced courses will bring corrections to this situation. Our test has shown that this is not the case and that students seem to reach an asymptotic conceptual level. Implications for teaching point to putting more emphasis on the qualitative aspect of physics in introductory courses and to reinforce it in advanced courses. Then, as Hewitt (1983) has claimed, the missing essential -a conceptual understanding of physics- will be restored.

NOTE: 6 female sophomore students had an average of 12.5%, much lower than that of the whole class. Three of them left engineering physics during the year for other department programs. However, the sample of female students might be too small to make any conclusions.

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APPENDIX

CON-PHY-TEST

EVALUATION OF CONCEPTUAL UNDERSTANDING IN PHYSICS

INSTRUCTIONS

A. The questions are qualitative and do not require long calculations. They have been chosen so that your level of conceptual understanding in physics (only mechanics and electromagnetism) can be evaluated.

B. The twenty (20) questions must be answered in forty-five (45) minutes.

C. Each question is worth five (5) points.

D. Explain your answers, but be brief. Give the main point, not details.

F. If there are more than one answer for one question, mention all of them.

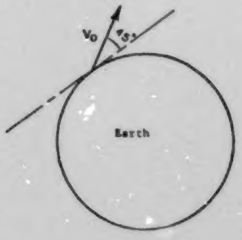
1. Starting with an initial velocity v_i a projectile reaches a final velocity v_f in a time $\Delta t = 10$ s. For which time duration does it have the intermediate speed $\frac{v_i + v_f}{2}$ if

a) $v_i = 10$ m/s and $v_f = 20$ m/s;

b) $v_i = 0.6\, c$ and $v_f = 0.8\, c$?

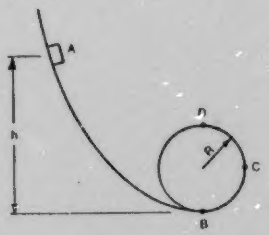
(*c is the speed of light in vacuum*)

2. From the ground a satellite is launched with a velocity v_0 and an angle of 45° above the horizontal. Draw its orbit qualitatively.



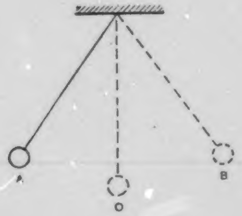
3. A body A is released from different heights h on the slide. Describe its motion qualitatively.

Friction is negligible and the body slides without rolling.



4. What is the weight of a 1-kg object placed at 10m from the center of the earth? The mean earth radius is $6{,}37 \times 10^6$m, the mass of the earth is $5{,}98 \times 10^{24}$kg and the gravitational constant is $6{,}67 \times 10^{-11}$N.m^2/kg^2.

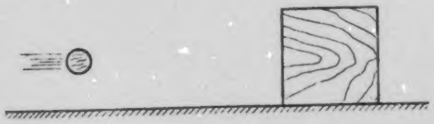
5. A pendulum oscillates between A and B. Are linear momentum and angular momentum conserved? And energy?

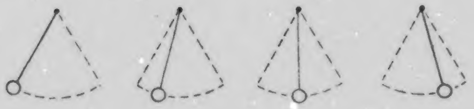


6. One fires at a block of wood two balls having the same mass, size and speed. One is made of rubber and the other aluminium.

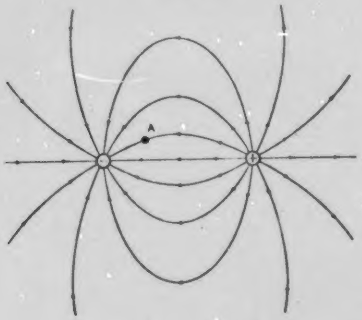
a) Which is most likely to knock the block over?

b) Which is most likely to damage the block?

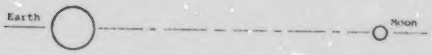




10. One releases a negative charge at point A. Represent its trajectory qualitatively.

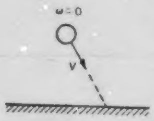


7. Represent qualitatively the resultant gravitational field produced by the earth and the moon.

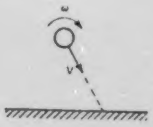


8. One throws a ball at a horizontal surface. For the three cases shown, indicate the direction of the frictional force and the resulting motion after the impact.

a)



b)



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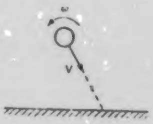


9. During the oscillation of a pendulum, the ball breaks loose suddenly at the four indicated positions. What will be the trajectories of the ball?

11. A sphere of radius R carries a charge Q. Compare the electrostatic energy if the charge is

a) punctual and at the center of the sphere;

b) distributed uniformly inside the sphere;

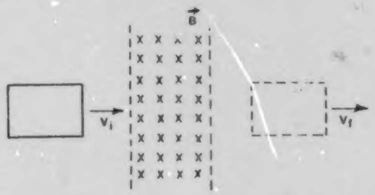
c) distributed on the surface of the sphere.

12. In mechanics one needs the relation $m = m(v)$, while in electromagnetism one has $q \neq q(v)$. That is why relativity is not involved in electromagnetism.

Comment this statement.

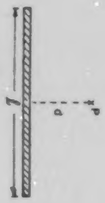
13. An electromagnetic wave is propagating in a medium. Does Faraday's law apply to the wave?

14. A rectangular metallic loop, entering at an initial velocity v_i in a uniform magnetic field, exits at a smaller final velocity v_f. Which work causes this slowing down? The magnetic field is perpendicular to the trajectory.



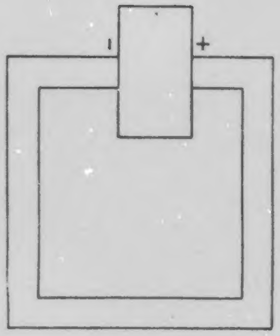
15. A point P lies along a perpenducular bisector of a straight wire segment of length l. Can one use

a) Gauss's law to calculate $\vec{E}(P)$ if the wire is uniformly charged?
b) Ampère's law to calculate $\vec{B}(P)$ if the wire carries a current?



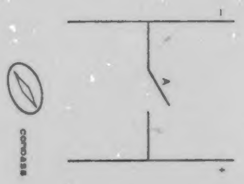
16. One turns on the ignition key in an automobile. How long will an electron take to migrate from the negative battery terminal to the positive?
(Suggested values: 10^{-9}s, 1/32s, a few seconds, a few minutes, a few hours)

17. Represent qualitatively the electric field for the circuit formed by a battery and a wire in which a direct current circulates.



18. The plates of a capacitor are charged + and - and then discharged to produce a spark. What would have happened if the plates had been pulled farther apart before being shorted?

19. One closes the switch A between the plates of a capacitor. What will be the effect on the compass?



20. A photon moves toward a rocket ship (v = 0.8 c). The astronaut measures the speed V, the momentum P and the energy E of the photon. What will be the new measures of V, P and E if the speed of the ship is increased?

EXPRESS
MONTREAL-VENUS

COMMENTS

1) For the test I will obtain ..../100.
(do not be too modest nor over-confident)

2) The group average will be ..../100.

3) What do you think of this test and of the nature of the questions?

IDENTIFICATION OF CERTAIN PRECONCEPTIONS THAT HINDER SCIENCE LEARNING: EXAMPLES INVOLVING ELECTRIC CIRCUITS

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About fifteen years ago a group called the Elementary Science Study group in Boston developed, among other beautiful units for learning science in elementary school, one that was called Batteries and Bulbs. This was so successful both with the children and with their teachers that many instructors since that time have used this approach as an introduction to the study of electricity also with college students. What I want to talk about today are some recurring problems that college students who have had no previous exposure to this subject matter, find in dealing with these simple electric circuits. First I will briefly describe some problems that have been identified as preconceptions or misconceptions in the literature. This is mostly the work of the groups at Amherst(1)(2) and at the University of Washington.(3) Then I will present some examples from my own work identifying a type of preconception that has not been dealt with before and pointing to problems in deciding when a difficulty is in fact a preconception. I will also offer a tentative grouping or organizing scheme of preconceptions according to their origins. Hopefully, this will also prove useful in the analysis of subject matter other than electricity.

The traditional first lesson when we use batteries and bulbs to study simple electrical circuits poses this problem: Given one flashlight bulb, one flashlight battery, and an assortment of wires, can you light the bulb with the cell? Typically, in a class of about 30 people it will take 20 minutes until everybody in the classroom has successfully and reproducibly been able to light that bulb. Some unsuccessful attempts are shown in the first figure. A common feature of these three drawings

----------Figure 1---------

is that all of them treat the bulb as single-ended and seem to assume that only the base of the bulb is electrically important.

Eventually the students realize that there are two special parts to the bulb and two special parts to the cell and that these must be connected for the bulb to light. At this point, when a qualitative model for a circuit is developed, another difficulty appears. Many students typically think that the battery provides a constant current that is used in the bulbs; in other words, that the bulbs act as sinks of current. This belief leads, for instance, to incorrect predictions of brightnesses of identical bulbs in simple circuits, since the order in which the current goes through the bulbs becomes important in determining their brightness.

A third example of students' difficulties with electric circuits is taken from the work of Fredette and Clement(2) who showed students a circuit like the one in Figure 2 and asked them to describe "what is going on" there.

----------Figure 2----------

A large number of students proceeded to explain the functioning of this circuit as if the shorting wire were not present. Clearly, the students must have seen the shorting wire, but they acted as if it were not there: they repressed their perception.

The next example I will give arises from our own work with what we call "mystery boxes," also a part of the original ESS Batteries and Bulbs. What are mystery boxes? These are boxes that have, for example, three exposed terminals. Inside the box are wires and bulbs. The student is asked to decide, with the aid of an external tester (which is made up of a bulb and a cell) how the box might be wired inside. Or, given the results of two tester connections, the student is asked to predict what will happen at the third. Figure 3 gives an example of three such questions.

----------Figure 3----------

We found that after weeks of manipulating circuitry, students were still having problems with questions like these. To better understand the nature of these problems we gave the students a very similar kind of puzzle with three cities. Just

-----------Figure 4-----------

like in the case of the mystery boxes, there are three questions: one in which the clues imply that the trip can be taken, a "yes" answer; one in which the proposed trip contradicts the clues implicitly, a "no" answer and one in which the proposed trip does not contradict the clues but is also not implied by them, that is to say, a "can't tell" answer. Thirteen students were interviewed, were told that these were three separate problems involving three cities each and were asked to answer the questions making use only of the information contained in the clues. Of the 13 students interviewed, 6 attempted to solve the puzzle within a logical framework, although only 1 of them was able to reason to a contradiction, that is, to answer Question 2 correctly: "No, because if I did I would be contradicting the clues implicitly." Two students attempted to solve the problem by looking for mechanisms that would explain the clues and thus show how the clues are to be used: They made assumptions about the existence or lack of airports in the cities or about the geographical location of the cities, whether they were close together, far apart, on a straight line, or forming a triangle.

Of the remaining 5 students, 3 answered the questions giving "Yes" answers to all three. They gave explanations of this sort: "The puzzle doesn't say you cannot," or "Yes, why not?" or "There's no reason given why you can't go; there are no barriers." One verbatim exchange was as follows:

Interviewer: "Are you saying that if the trip is not explictly mentioned you automatically assume that it is allowed?"

Student: "I guess so; that suits my personality perfectly."

The last 2 students gave "No" answers to all three questions. They gave arguments of this sort: "There is no mention of a trip made between these two places; therefore, from this information, it cannot be done or at least it isn't known to be done," or "The trip could possibly be made, but chances are it cannot be." One of the interviewes went like this, verbatim:

Student: "It's like when you take exams, the questions are true or false. Unless all parts of the statement are true, then you know that the answer is false."

Interviewer: "So you'd say that in all your student experience with tests you've been programmed to consider all that is not explicitly allowed or labeled 'true' as forbidden or untrue?"

Student: "Yes, definitely."

Interviewer: "Would you say that this is true also in your personal life? Say that when you were small if your mother did not explicitly say you could go to play after school it meant automatically that you couldn't?"

Student: "Oh, yes. Goodness, I'm learning something about myself!"

There is no way that these kinds of idiosyncratic approaches to the solution to these problems could have possibly been gleaned from the written responses that were first produced. Even the first oral responses did not uncover the full force of the personal belief system that was guiding them. I should here clarify that the protocol was to give the written question to the student, give the student as much time as s/he needed alone and then come back and go over the answers in an interview fashion. The numbers are striking: one-third of the class chose responses to the problems that were consistent with their own set of internal moral determinants. In the absence of any explicit clues one set of people decided that, "If I am not told explicitly that it is allowed, then it is forbidden." The other set of people said "If I am not told explicitly that it is forbidden, then it is allowed." We posed a logical problem, and these students chose to solve it by analogy with past experience: not by analogy with their experience with other physical systems, but by extension of their system of ethical behavior, their code of do's and don't's.

Just like some of the other preconceived modes of approach when entrenched became very resilient, so it is with this one. We attempted to teach the students how to solve the three-city problems by using diagrams with arrows to indicate trips and clarifying the meaning of "yes", "no" and "can't tell" in this context. And yet when these 13 students were given another similar problem, namely the Karplus island puzzle,(4) only 4 of them could solve it correctly.

So far I have reviewed four kinds of difficulties that the students find in dealing with circuits and the ways that they proceed in order to find answers. In the examples given the student had no guidance with respect to the ways and means for coming up with the solution. Faced with such lack of direction, the students searched their experience to find that which they felt might best help them solve the problems at hand. In the case of the mystery boxes the guiding experience stemmed from their code of conduct. Let us see in the other cases what it was.

In the case of lighting a bulb, some students who persisted in doing so as shown in Figure 1 compared their set-up to a flashlight connection. In a flashlight all that is evident when it is put together is that the cells are in touch with the bottom of the bulb; the connection between the flat end of the cell and the side of the bulb is made by the body of the flashlight case or by strips of metal which may not be directly perceived as equivalent to wire connections. A few students mentioned thinking of a lamp where there is one cable that leads from the light source and plugs into the wall or power source and there is no obvious return wire; these students were unaware that the cable really contains two wires. In both these cases, the flashlight and the lamp, the students are making appeal to electric circuitry that they are familiar with and in which there is light. Their preconceptions here are based on previous experience with similar physical objects.

Now let us go to the model of a circuit where the bulb is seen as a sink of electricity rather than as a circuit element through which the current passes, coming in at one end and leaving at the other. Students will often quote other instances, non-electrical in nature, that might lead them to think of the bulb as a sink with only an input and no output. For example, pouring liquid from a can into a glass; the can is the cell, the glass is the bulb and the semblance of a closed circuit or at least of a double-ended cell is kept, since for the water to come out of the bottle it is necessary for air to be going into the bottle.

Consider now the example having to do with the "invisible short," (Figure 2) the shorting wire that was there but that one-third of the class did not take into consideration in the explanation. We carried out a similar set of interviews with some of our students who had been through five weeks of "messing about" with batteries and bulbs and therefore had been exposed time and time again to the sneaky presence of shorting wires. The proportion of our students who did not see the shorting wire was much less; in fact, there were only 2 students out of 17 who failed to take account of the shorting wire contrasted with 5 out of 15 in the original interviews. I would suggest the the students who were interviewed by Fredette and Clement had the usual student expectations that all problems asked would have a solution and that nothing will be introduced that is extraneous to working out the problem in order to get the solution. In the words of one of our students: "If these elements will not do anything, then why bother to put them in there?" meaning the elements in parallel with the shorting wire. This is a problem then, where the preconception is not related to the physics setup, but rather has to do with student expectations about the situation.

The four examples I have given point to preconceptions of very diverse origins. We can talk of four different types of preconceptions according to whether they arise from:

1. appeal to previous experience with similar physical objects
2. analogies drawn with different physical phenomena

3. situational expectations
4. moral determinants

A preconception implies a system, a set of coordinated thoughts, a knowledge structure off which the student works. What is interesting about some of the examples we have given today is that they certainly do imply a system of coordinated thoughts but that these have little, if anything, to do with physical science; rather, they are based on belief systems external to the subject matter iself. And their penetration into the problem-solving activity may be very subtle indeed and difficult to detect.

Now I will turn my attention to another difficulty that students experience with their work with circuits. Assume that a student knows how to light one bulb with a cell or two, that is to say, that s/he can confidently use the operational rule that the only thing that matters in lighting a bulb is that the two special parts of the cell be connected respectively to the two special parts of the bulb. If this is so, then the student knows that a closed circuit with a lit bulb (a) remains invariant under the following operations;

----------Figure 5----------

reflections (b), rotations (c), displacement of the system as a whole;
symmetry of bulb positioning with respect to the cell (d);
transposition of the side and bottom connection of the bulb (e, f);
transposition of the flat-end and bump-end of the cell connection with respect to the bulb (g and h) (but not with respect to another cell);
change in length of the wires involved; warping (i); angling (j); or bending of the wires;
type of insulation, color of insulation. The list is infinite.

From the point of view of the operational definition of a closed circuit with a lit bulb as an indicator, all the circuits in Figure 5 are equivalent. Not equal; equivalent.

Dealing with this type of equivalence in a classroom situation seems to require explicit clarification, not only of that which does matter but also of the many items that the student might think do or could matter but don't. It isn't altogether surprising that it should be so. After all, things that don't matter in one set of circumstances do matter in others: coils in wires don't matter in this work but matter in the work on magnetism, orientation of the circuit in a horizontal plane doesn't matter in this work but matters when the earth's magnetic field affects compass readings near coils in circuits, length of copper wires doesn't matter now in class but length of nichrome wires will matter when introduced.

Here arises another problem: We found that students who had predicted correctly but with difficulty what would happen in a certain circuit, did not recognize it as being the same entity when it was rotated. They laboriously went through the whole process of predicting again as if it were a new problem. They seemed to understand that spatial rotation of the circuit does not matter but were not able to recognize it when they saw it. This behavior made us suspect a lack in spatial ability (5) in these students, something different from an understanding of the equivalence itself, but rather at the visual processing level. In order to test this outside the realm of circuitry, we devised a very simple conservation exercise where a student has to see that the shape and size of a geometric figure are not altered under displacement and rotation in the plane.

----------Figure 6----------

Of the 65 students tested, 43 gave perfectly correct answers, reporting three independent triplets of superimposable triangles, namely ACI, BFH, and DEG. The remaining students were interviewed on a one-on-one basis to better understand the nature of their responses. Of these, 19 students gave their answers as pairs of triangles because they did not perceive the third one as belonging with the other two.

The question then comes up: when a triad of triangles is reported as a diad or pair, is there any one triangle that is consistently more difficult for the students to perceive as belonging to the set? For each set of three triangles one of the three pictures is obtained by rotating the first one by 90° (A and C, B and H, D and G). The other is a rotation of arbitrary angle. None of the pictures is a result of a reflection which might have caused additional difficulties. The explanations that students gave when asked about their reasoning in arriving at a decision were of the following types: "H looks thinner than B and F," or "D looks taller than E and G," or "B looks like all its sides are equal and F and H do not." No one set of explanations in terms of angles or rotation (for example, is 90° easier to perceive than an arbitrary angle?) or predominant perception of verticalicality or horizonality will unify these responses.

Some of the students were asked if they could have used their pencils or a piece of paper to verify "tall" or "thin." The thought of actually manipulating the figures had not occurred to them at all. The idea of obtaining one from the other by rotation, mental or manipulative, was even more distant from anything they might have tried. For the people who were having trouble visualizing the equivalencies, it was necessary to cut the figure out and physically show that it could be superimposed on the seemingly taller or longer figure.

In our work with the circuits one might have argued that the lack of recognition of the rotated circuit was due to a preconception on the part of the student about what does matter and what doesn't matter in establishing equivalences. Our work with triangles, however, suggests a perceptual problem: poor spatial visualization, problems with actual manipulation of whole configurations. Our numbers indicate that almost one-quarter of the class had difficulties of this kind.

Today I have tried to give some idea of the variety of types of thinking that can hinder students in a science problem-solving situation. I would like to end by stressing

-- that difficulties that seem due to preconceptions may in fact be due to a lack in a specific ability, such as spatial visualization.

-- the importance of recognizing when the student is doing science and when, in fact, s/he is appealing to alternate frameworks that have to do with personal belief systems that are not related to the subject matter at hand.

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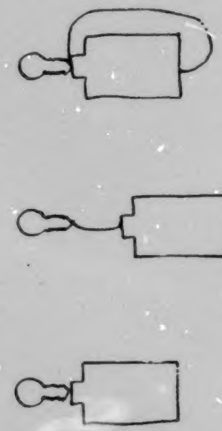


Figure 1. Attempts at lighting a bulb

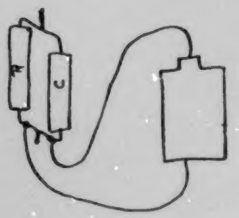
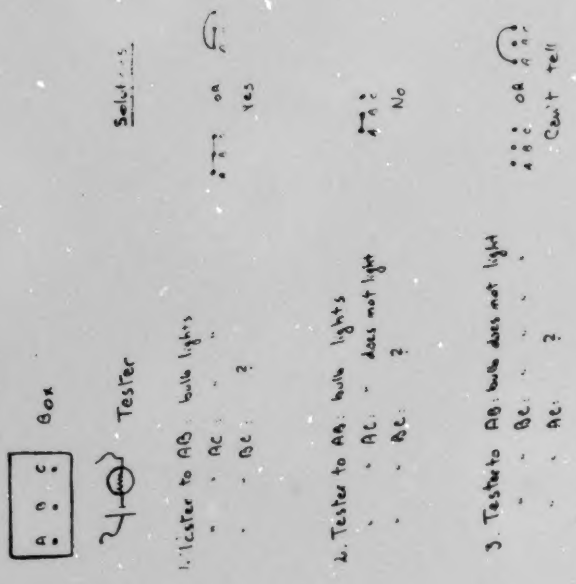


Figure 2. The invisible short



1. Tester to AB: bulb lights
" " AC: " "
" " BC: ?

2. Tester to AB: bulb lights
" " AC: " does not light
" " BC: ?

3. Tester to AB: bulb does not light
" " BC: " " " "
" " AC: ?

Figure 3. Mystery Box Problems

These puzzles are about travel between 3 cities. Carefully read the lues about possible trips. Trips may be direct or include stops and plane changes. hen a trip is possible it can be made in either direction.

	Solutions
1. Consider 3 cities: Atlanta, Boston and Chicago You can fly between Atlanta and Boston You can fly between Atlanta and Chicago Can you fly between Boston and Chicago?	Yes
2. Consider 3 other cities: Montauk, Napa and Omaha You can fly between Montauk and Napa You cannot fly between Montauk and Omaha Can you fly between Napa and Omaha?	No
3. Consider 3 other cities: Washington, Yuma and Xanadu You cannot fly between Washigton and Xanadu You cannot fly between Yuma and Xanadu Can you fly between Washington and Yuma?	Can't Tell

Figure 4. Three City Puzzle

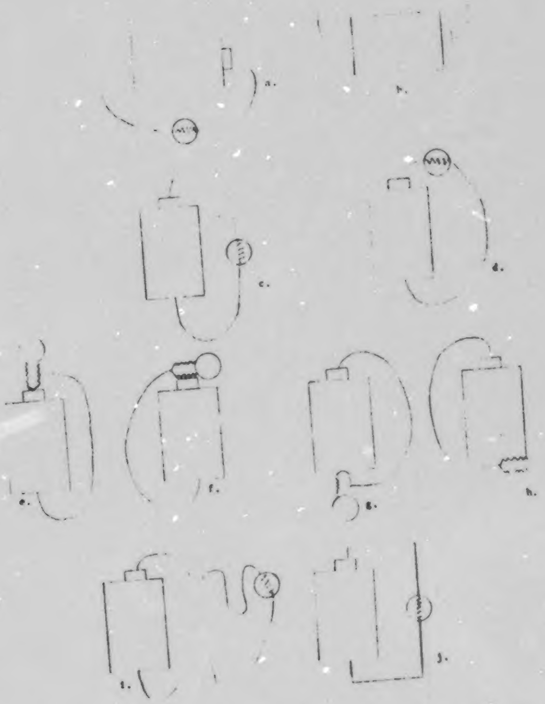


Fig. 5: Electrically equivalent circuits.

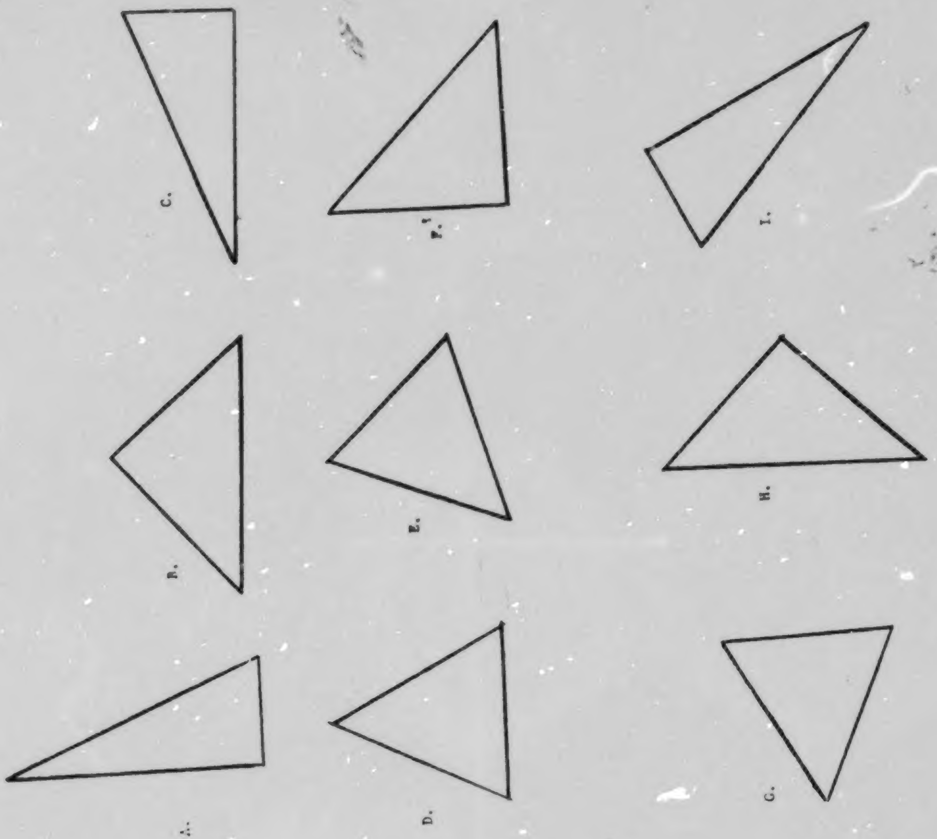


Fig. 6 Triangle test: "Of the following, name those that you think could be superimposed perfectly on each other."

NOT ALL THE WRONG ANSWERS STUDENTS GIVE REPRESENT MISCONCEPTIONS: EXAMPLES FROM INTERVIEWS ON GEOMETRICAL OPTICS

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For the past several years the Physics Education Group at the University of Washington has been engaged in an investigation of student understanding of various topics in introductory physics. One of our goals has been the identification of specific conceptual difficulties. The topics investigated have included: kinematics, dynamics, electrical circuits, heat and temperature, and, most recently, optics.

We have used a number of different methods in our research. In much of our work, a method we call the individual demonstration interview has played an important part. Briefly stated, an individual demonstration interview is a one-on-one discussion between a subject and a researcher about an observed physical system. The subject is shown some apparatus, is asked to manipulate the apparatus or make a prediction, and then explain his reasoning. Although not without its problems, this method, and others like it, have a number of advantages for in-depth explorations of conceptual understanding. One of these advantages is the possibility of probing beyond a student's initial response to a question or a task. It is this aspect of the method we will illustrate in this paper by describing some of our work on geometrical optics. In addition to helping us identify specific difficulties students have with the interpretation of images formed by lenses and mirrors, our use of the individual demonstration interview has provided a number of other insights. One, in particular, has led to the title of this paper: "Not All The Wrong Answers Students Give Represent Misconceptions."

In discussing some of the result of our work, we will use the term "misconceptions" in a rather broad sense to include the ideas students have about the concepts of physics that are not fully consistent with the physicist's view of these concepts. Furthermore, we will refer to a student as holding a misconception only when the student seems to exhibit, more or less, the same incorrect idea throughout a task or on more than one task.

In this paper we will discuss five of the tasks that we have used this year during interviews with 90 students enrolled in both the algebra-based and calculus-based introductory level college physics courses at the University of Washington. Each interview lasted between 40 and 50 minutes and dealt with the image-forming properties of mirrors and lenses. About half of our subjects had already studied the material in class, and they represent the "post" subjects in our investigation. The other half, representing the "pre" students, had not yet studied the material in their college physics classes. However, most of them were somewhat familiar with the ideas from either life experiences or from a previous high school physics course.

In this set of interviews, after we ask each question, the student makes his prediction and explains his answer. We do not allow the student to try the actual experiment. Instead, we move on to the next task. We do not want students' responses to later tasks to be influenced by what they may learn by trying out one of the earlier tasks. (After the interview session is completed, we do allow the students to try anything they want and some good "teaching" does take place at that time.)

The first task involves images in a plane mirror. See Figure 1. The interviewer and subject are sitting in front of a plane mirror (about 20 cm by 30 cm). A dowel rod stands between the subject and the mirror. The subject is asked to look at the image of the rod and to tell where the image is located. The interviewer then asks: "Put your finger on top of where the image is located." (Subject does this) "Please leave it there while I ask you this next question. Suppose you were sitting over here where I am, about two or three feet to your left, and I asked you the same question; namely, put your finger on top of where the image is located. Would you then be putting your finger at the exact same place it is now, or would you be putting your finger at a different place?"

After the student makes a prediction, the interviewer first asks for a verbal explanation and then suggests that the student make use of the paper and pencil on hand to try to explain his or her response.

The correct answer to this question is that the student should put his finger in the same place. About 50% of the pre-students and about 30% of the post-students responded incorrectly and gave an "explanation" of their wrong answer. Figure 2 shows an excerpt from an interview with a pre-student enrolled in the calculus-based course. This student, as well as many others, used a strategy we call "line-of-sight" to predict the location of the image. Figure 3 shows a typical diagram used by students invoking a "line-of-sight" strategy. These students predicted that the image position would move to the right as they moved to the left.

There were a number of post-students who initially gave an incorrect response, justified it verbally, but then changed their mind after they used a pencil and paper to draw a ray diagram. Figures 4A and 4B show an excerpt from a post student. This student was able to use the ray diagram as a way of bringing to bear information that he had learned in his physics course. About 25% of the post students responded in the same way. Figure 5 shows a summary of the interview data for this task.

After the subject finishes explaining his or her reasoning to the initial task, the interviewer then moves on to the next question. The mirror is covered, and the rod is moved so that it stands in front of and to the right of the mirror. The situation is sketched in Figure 6. The interviewer says: "Suppose I were to uncover this mirror. From where you are sitting, would you be able to see an image of the rod in the mirror? ... Would I be able to see an image of the rod in the mirror?" After the subject responds to each of the two questions, the interviewer asks for an explanation.

The correct response is that the subject cannot see the image of the rod but the interviewer can. Figures 7 and 8 are excerpts from interviews with a pre- and post-student who use "line-of-sight" reasoning. Figure 9 is a summary of the interview data for this task. There are some interesting observations that can be made. In this case a significantly greater number of post-students than pre-students answered correctly. The YES/YES response of the post-students, although incorrect, was interesting. These students drew a correct ray diagram (using the law of reflection) to explain why the interviewer would be able to see the image. However, in drawing a ray diagram to explain how *they* could see the image, they drew a ray from the rod to the mirror and back again to their eye, thus violating the law of reflection. These students seemed to have a strong underlying belief that they would see the image along their line of sight, and they adjusted their ray diagrams accordingly (and incorrectly). The 37% of the pre-students who responded YES/NO were using the line-of-sight strategy to explain both answers.

For the next task the interviewer holds up the rectangular-shaped plane mirror about three feet in front of the student and asks how much of himself the student can see. Typically, the student says he can see from the top of his head to about eight inches below his neck. See Figure 10. Then the interviewer asks the following: "Is there anything you could do to enable you to see more of yourself in this mirror?"

As it turns out, other than tilting the mirror or rotating it 90 degrees about its axis, there is NOTHING one can do to see more of oneself in the mirror. However, about 90% of the pre- and 70% of the post-students gave an incorrect answer. They said that they could see more of themselves by moving further away from the mirror. Moreover, they were very confident in this prediction. Most were absolutely sure that they had experienced it. What we found most interesting, however, was not this incorrect prediction, but rather the reasoning used to justify the prediction. Most of the explanations were similar to the excerpts in Figures 11-13. Figure 14 schematically represents the two most common lines of reasoning used by the students. In the upper diagram the student considers himself to be standing in front of the mirror and thinks the mirror as an eye "looking at him." The closer he is to the mirror, the less the mirror sees of him; and the further away he is, the more the mirror sees him.

Another point of view is for the student to think of his image as somehow "fitting into" the mirror. It is the student's experience that objects appear smaller the further away they are. Therefore, he reasons that as he moves further from the mirror his image gets smaller. Thus more of his image "fits into" the mirror. The student overlooks the fact that as he moves further back, the mirror also appears smaller in the same proportion as his image does. Figure 15 shows the summary data for this interview task.

The next two tasks deal with the image-forming properties of a converging lens. The equipment consists of an illuminated object, a converging lens, and a screen mounted on an optical bench. The object is a clear bulb with a horseshoe-shaped filament. The subject is asked to describe what he sees on the screen, which is an enlarged and inverted image of the object. The interviewer then asks: "Suppose I were to remove the lens, leaving the object and screen where they are. Would anything change?" After responding, the subject is asked to explain his reasoning. See Figure 16.

The responses were interesting because only a few students recognized that without the lens there would be no image on the screen. This was especially true among the students interviewed before instruction. The immediate response of the majority of students was that if the lens were removed, the image would become erect. Now one might be immediately tempted to interpret that prediction as indicating that the students did not recognize that a lens was necessary to form an image. However, it is also possible that this response was somewhat idiosyncratic to the apparatus. Perhaps the student, who was looking at the inverted image on the screen, may have been concentrating on the inverting property of the lens rather than thinking of its essential role in focusing the light to form an image. To be sure that the student was not merely distracted by a strong perceptual impression but indeed really did not recognize that the lens was necessary to focus the light, we needed to probe further. As it turned out after careful questioning, many students still felt that even without the lens there might be an erect image on the screen, although it might be fuzzy. Some justified their prediction by claiming that without the lens the light would just go in straight lines to the screen. The excerpts in Figure 17 and 18 illustrate this misconception, and Figure 19 presents a summary of the interview data.

At the end of the academic year, we were able to give some of our tasks in a written multiple choice format as part of the final examination in a large lecture section of calculus-based introductory physics. We were interested in seeing how the percentage of incorrect responses in the written format compared with that obtained through the interviews. Figure 20 shows the multiple choice question that was analogous to the task in which the lens was removed. The numbers at the bottom of the page represent the percent of the 170 students who chose each answer. As can be seen from the data, about the same percent of students (41%) gave the same incorrect response on both the interview and written task.

The next task was designed to determine whether students believe that the entire lens surface is necessary to form a complete image. In this task the interviewer holds up an opaque card near (but not covering) the lens and asks: "Suppose I were to bring this card over and cover the upper half of the lens, leaving the lower half uncovered. Would anything change on the screen?" See Figure 21. The interviewer then asks for a detailed explanation.

The vast majority of the students predicted that half the image would disappear. (In actual fact the entire image remains intact and only its brightness decreases.) Many of the pre-instruction students, in particular, claimed that the half that would vanish would depend on whether the front upper half or the back upper half of the lens were covered. Figure 22 shows an excerpt from an interview with a post-student. (In that interview an illuminated slide of a cross-shaped figure was used as the object for the lens.)

Many students do not seem to realize that light leaves in all directions from every point on the object and strikes every point on the lens. Therefore, any portion of the lens is sufficient to form a complete image. Many of the students who drew ray diagrams to justify their incorrect predictions often showed only those rays which leave a point at the top and a point at the bottom of the object and travel parallel to the principal axis. Figure 23 shows a commonly drawn diagram, in which the student draws only one ray from each of these two object points.

Other students, who drew correct ray diagrams, also arrived at the wrong conclusion. See Figures 24 and 24a. These students drew the ray parallel to the principal axis and the ray through the center of the lens. They seemed to believe that these rays are necessary to form an image when, in fact, they are sufficient but not necessary. The students may also have been misled because they omitted the third of the special rays that help locate the position of the image. (This ray passes through the focal point and strikes the bottom of the lens.) Figure 25 and 26 show a summary of the data from the interviews and from the written multiple choice examination.

In this paper we have described five tasks that were given during individual demonstration interviews to students enrolled in introductory college physics courses. The tasks involved the formation of images by plane mirrors and converging lenses. Student performance revealed a number of commonly held misconceptions. These are summarized below:

(1) You see images in mirrors along your line of sight.

(2) How much of your body you can see in a mirror depends on your distance from the mirror.

(3) Light from an object can go straight to a screen and form an image on the screen without the presence of a lens.

(4) The two special rays, the ray leaving the top of the object and traveling parallel to the principal axis, and the ray passing through the center of the lens, are necessary (and not merely sufficient) to form the entire image on the screen. (post-students only)

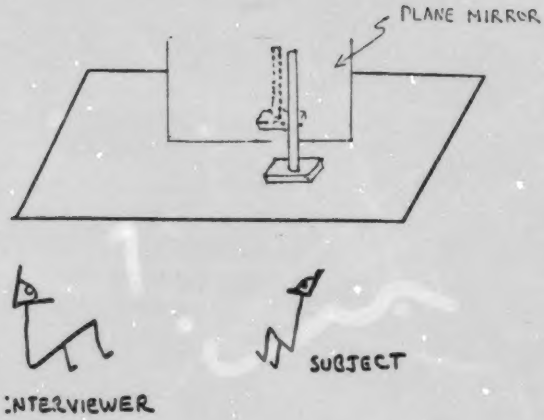
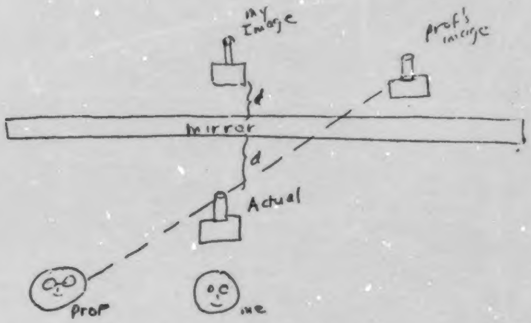


FIGURE 1

I: ...IF YOU WERE TO DO THAT WOULD YOU THEN BE PUTTING YOUR FINGER IN THE EXACT SAME PLACE THAT YOUR FINGER IS NOW? OR WOULD YOU BE PUTTING IT AT A DIFFERENT PLACE?...

S: IT WOULD BE AT A DIFFERENT PLACE, I THINK. ...



I: OK. WHY DON'T YOU EXPLAIN YOUR DIAGRAM. EXPLAIN TO ME WHY YOU DREW THE IMAGE I WOULD SEE OVER THERE.

S: UH, HMMM. LET ME THINK. IT SEEMS THAT IT WOULD BE PRETTY MUCH IN A STRAIGHT LINE OF YOUR VISION, NO MATTER WHAT ANGLE YOU'RE AT, THAT THE IMAGE WOULD BE IN A STRAIGHT LINE OF VISION. AND I TRIED TO MAKE THIS AS STRAIGHT AS POSSIBLE WITH YOUR VISION LINE AND SAME WITH MY VISION LINE.

FIGURE 2

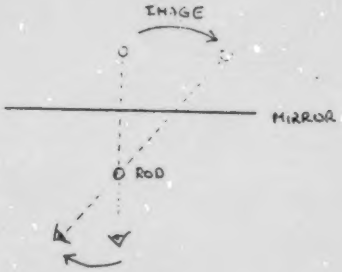


FIGURE 3

I: IF YOU WERE SITTING OVER HERE WOULD YOU BE PUTTING YOUR FINGER IN THE EXACT SAME PLACE WHERE IT IS NOW, OR WOULD YOU BE PUTTING IT IN A DIFFERENT POSITION.

S: I WOULD BE PUTTING IT IN A DIFFERENT POSITION.

I: ALRIGHT, YOU CAN TAKE YOUR HAND AWAY. I WANT TO SEE IF YOU CAN EXPLAIN OUT LOUD HOW YOU'RE THINKING THERE.

S: BECAUSE IF YOU'RE IN A DIFFERENT SPOT THE RAYS ARE REFLECTING OFF THE MIRROR DIFFERENTLY. YOU'RE SEEING IT AT A DIFFERENT ANGLE SO THE IMAGES WOULD SEEM TO BE IN A DIFFERENT PLACE.

I: OK. AND HOW CONFIDENT ARE YOU IN YOUR PREDICTION?

S: PRETTY CONFIDENT.

I: DO YOU THINK YOU COULD TRY TO JUSTIFY THAT BY DRAWING ME A DIAGRAM.

S: YEA.

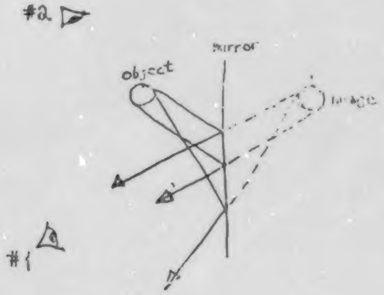
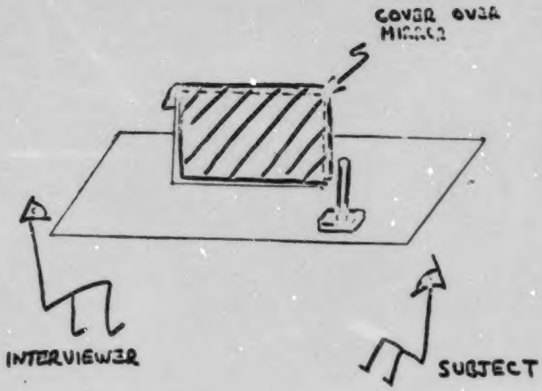


FIGURE 4-A



"IF I WERE TO UNCOVER THE MIRROR, WOULD YOU SEE AN IMAGE OF THE ROD? . . . WOULD I SEE AN IMAGE?

FIGURE 6

S: OK. THESE ARE THE LIGHT RAYS REFLECTING OFF THE OBJECT AND THE ANGLE OF REFLECTION IS THE SAME AS THE ANGLE OF INCIDENCE. THE IMAGE IS RIGHT THERE. NOW DO YOU WANT ME TO DRAW IT FOR SOMEBODY ELSE? MAYBE I'M WRONG.

I: PARDON ME. MAYBE YOU'RE WRONG, YOU SAID. WHAT SEEMS TO BE THE PROBLEM?

S: WELL IT SEEMS LIKE THEY'RE ALWAYS GOING TO INTERSECT IN THE SAME PLACE NO MATTER WHERE, WHERE YOU'RE LOOKING AT IT FROM.

I: WHAT DOES THAT MEAN?

S: THAT MEANS THAT ITS GOING TO LOOK THE SAME TO ANYBODY. LOOKING AT IT FROM DIFFERENT ANGLES, THE IMAGE WOULD STILL BE IN THE SAME PLACE.

I: SO YOU FEEL NOW YOUR ORIGINAL STATEMENT IS NOT CORRECT?

S: YEA, ONCE I DREW IT UP. BECAUSE I DON'T SEE HOW I COULD DRAW THIS DIFFERENTLY. THE RAYS ARE STILL GOING TO REFLECT OFF AT EQUAL ANGLES.

I: SO YOUR CONCLUSION IS NOW DIFFERENT. AND HOW CONFIDENT ARE YOU IN YOUR NEW CONCLUSION?

S: REASONABLY CONFIDENT, BECAUSE I SEE THAT THEY'D STILL INTERSECT IN THE SAME PLACE.

I: OK. WHY DO YOU THINK THAT YOU GAVE A DIFFERENT ANSWER EARLIER WHEN YOU THOUGHT OF THAT?

S: WELL IT APPEARS DIFFERENTLY WHEN YOU DRAW IT OUT. I DON'T KNOW. I CAN'T REALLY SAY EXCEPT THAT IT SEEMED TO ME, JUST KIND OF THE WAY I CONCEPTUALIZED IT, THAT IT SEEMED THAT WHEN YOU LOOK AT IT FROM THAT SIDE THAT THE IMAGE WOULD SEEM MORE OVER HERE. I GUESS WHEN YOU LOOK AT THINGS, JUST REGULAR OBJECTS, YOU SEE THEM DIFFERENTLY THAN I DO FROM WHERE YOU ARE. SO I GUESS THAT'S MAYBE HOW I LOOKED AT IT.

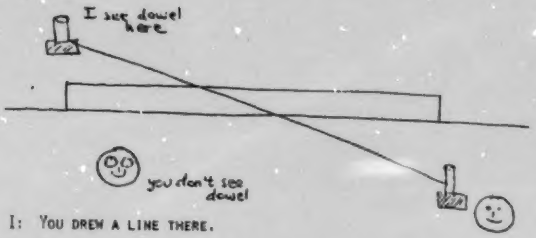
FIGURE 4B

I: I HAVE COVERED THE MIRROR AND I'VE MOVED THE ROD SO THAT IT'S NOW IN FRONT OF AND TO THE RIGHT OF THE MIRROR. NOW IF I WERE TO UNCOVER THE MIRROR WOULD YOU SEE AN IMAGE OF THE ROD IN THE MIRROR? WOULD I SEE AN IMAGE OF THE ROD IN THE MIRROR?

S: I WAS JUST THINKING THAT, KEEPING IN REASONING WITH MY FIRST THOUGHT LINES HERE, I WOULD BE ABLE TO SEE IT BECAUSE THE DOWEL WOULD END UP BEING RIGHT OVER THERE AND THE REFLECTION WOULD BE IN THE MIRROR, BUT BECAUSE YOU'RE LOOKING AT IT THIS WAY THERE'S NOTHING IN YOUR SIGHT LINE.

I: SO WHAT IS YOUR PREDICTION?

S: THAT I WOULD BE ABLE TO SEE IT BUT THAT YOU WON'T.



I: YOU DREW A LINE THERE.

S: UH, HMM ITS A SIGHT LINE.

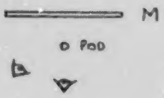
I: OK, ALRIGHT. NOW HOW CONFIDENT ARE YOU IN YOUR PREDICTION?

S: PRETTY CONFIDENT, YEA, PRETTY CONFIDENT UNTIL PROVEN OTHERWISE I GUESS.

FIGURE 7

INTERVIEW DATA SUMMARY

ME MIRROR TASK: WOULD YOU PUT YOUR FINGER IN THE SAME PLACE?

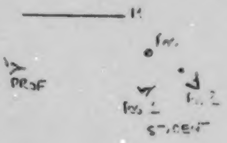


	PRE (N=28)	POST (N=36)
ME PLACE (CORRECT)	46%	42%
IFFERENT PLACE	50%	31%
IFFERENT PLACE ⟶ SAME PLACE (CHANGED ANSWER)	0%	27%
SURE	4%	0%

FIGURE 5

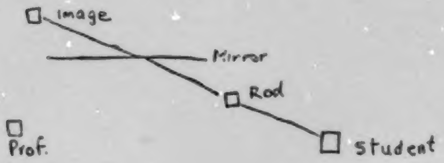
I: SUPPOSE I WERE TO UNCOVER THE MIRROR. WHERE THE ROD IS SITTING NOW, WOULD YOU SEE AN IMAGE OF THE ROD IN THE MIRROR?

S: HMMM, IT WOULD DEPEND ON HOW I WAS FACING. IF I WAS FACING THE ROD STRAIGHT ON, LIKE THIS, NO. (POSITION 1). IF I WERE TO LOOK STRAIGHT DOWN THE ROD, YES, I WOULD SEE THE IMAGE (POSITION 2).



I: I WONDER IF YOU CAN EXPLAIN TO ME WHY THAT IS.

S: OKAY. (DRAWS SKETCH). I'M SITTING HERE, THE ROD'S SITTING THERE, AND MY LINE OF VISION PASSES STRAIGHT TO THE ROD TO THE MIRROR AND I WOULD SEE THE IMAGE OF THE ROD DIRECTLY BEHIND THE MIRROR THE SAME DISTANCE. (THE DISTANCE FROM THE ROD TO THE MIRROR EQUALS THE DISTANCE FROM THE MIRROR TO THE IMAGE).



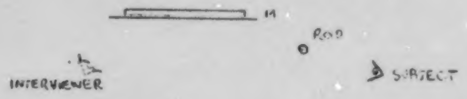
I: OKAY. NOW, IF I UNCOVERED THE MIRROR, WOULD I SEE AN IMAGE OF THE ROD IN THE MIRROR, IF I LOOKED IN THE MIRROR?

S: FROM WHERE YOU'RE SITTING? NO, YOU WOULD NOT SEE AN IMAGE IN THE MIRROR. THE ROD IS NOT IN YOUR LINE OF VISION. IT'S NOT IN YOUR LINE OF VISION AND IT'S NOT DIRECTLY IN FRONT OF THE MIRROR.

FIGURE 8

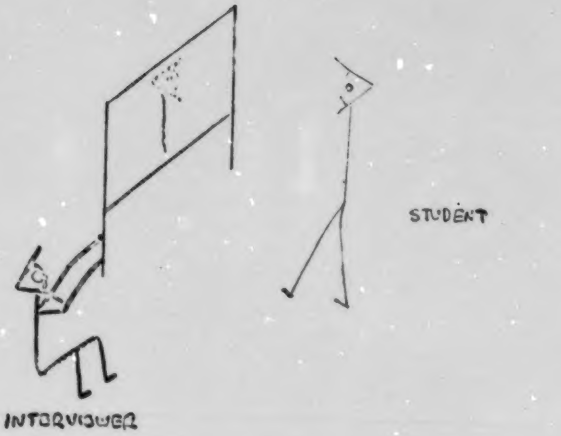
INTERVIEW DATA SUMMARY

LANE MIRROR TASK: IF MIRROR WERE UNCOVERED WOULD SUBJECT SEE IMAGE? / WOULD INTERVIEWER SEE IMAGE?



	PRE (N=11)	POST (N=24)
I/Y (CORRECT)	27%	63%
HANGED MIND → N/Y	27%	8%
/N	37%	4%
/Y	0%	25%
/N	9%	0%

FIGURE 9



"IS THERE ANYTHING YOU COULD DO
TO ENABLE YOU TO SEE MORE
OF YOURSELF IN THIS MIRROR?"

FIGURE 10

S: BECAUSE IF YOU HAVE THE SURFACE OF THE MIRROR LIKE HERE, EVERYTHING THAT'S REFLECTED ON TO IT COMES AT A CERTAIN ANGLE. OKAY. SO IF I'M HERE, YOU CAN ONLY SEE A PART OF ME. BUT IF I MOVE BACK SO THAT MY WHOLE BODY IS WITHIN THE ANGLE, YOU'RE GOING TO SEE MY WHOLE BODY.

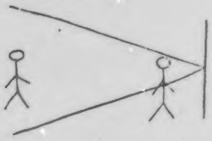


FIGURE 11

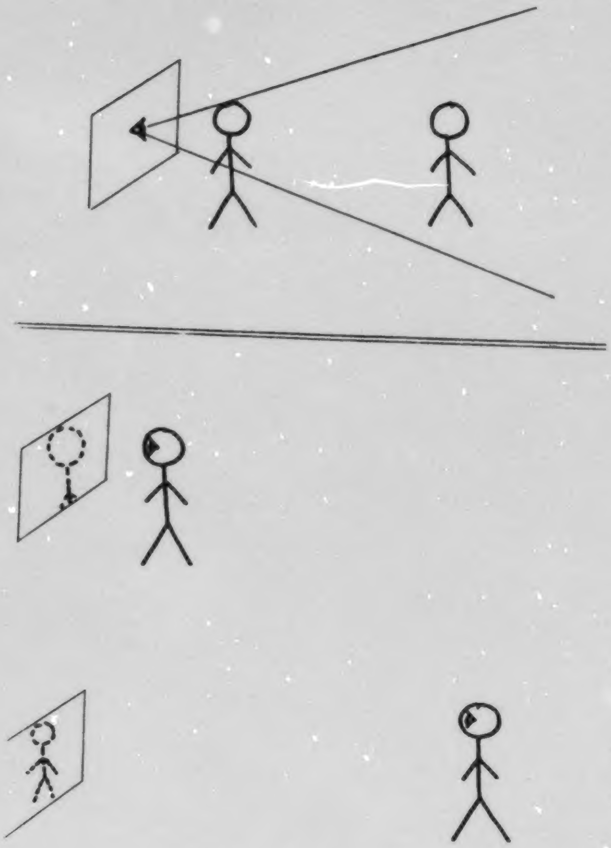


FIGURE 14

INTERVIEW DATA SUMMARY

MIRROR TASK: What can you do to see more of yourself?

	PRE (N=37)	POST (N=21)
Nothing (correct)	5%	14%
Move back	92%	72%
Other	3%	14%

FIGURE 15

I: Can you explain why moving further away will enable you to see more of you?

S: Because as I go further away, my image becomes smaller and is able to fit into the mirror, but as I get close, my image is much larger. And the mirror is a fixed size.

I: Do you feel confident in that answer, that that's a good explanation?

S: It's very general, but yes.

I: So, let's go over it one more time, maybe in your own words again.

S: The further away I get, the smaller my size or my image is to the mirror, relative to the mirror. So the mirror continues to reflect the same amount that it did before, but my relative size is smaller.

FIGURE 12

I: Is there anything that you could do that would enable you to see more of yourself in this mirror?

S: Back up.

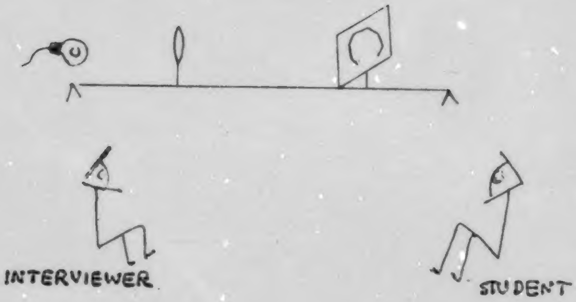
I: Back up. Okay. I'd like you to try to explain to me why you believe that backing up would enable you to see more of yourself in this mirror.

S: Because I've experienced the phenomenon, and I know that's what happens.

I: Can you try to explain as best you can why you believe that would be the case?

S: If a person is further away from you, you can see more of his body within a given field of vision. Like, if you're looking through a little square that's like an inch square through a piece of paper, if he's really close to you, then you can only see a little part of him. But if you back up far enough, you can see his whole body through that little square in that piece of paper. And it's similar to a mirror, I guess. Maybe that's—yes, because the mirror is only giving you a picture of a certain size. And if you back up, the further away you are, the smaller you appear, and so more of you fits in the space that size.

FIGURE 13



"SUPPOSE I WERE TO REMOVE THE LENS, LEAVING EVERYTHING ELSE THE SAME. WOULD ANYTHING CHANGE?"

FIGURE 16

I: Suppose I were to take the lens, and take it off, and put it on the table, leaving everything else the same. Would anything change?

S: Yes, the horseshoe would return back to its original-- to the shape that you would expect it to be without the lens, which is, right side up.

I: Can you justify or explain your reasoning?

S: Um, the lens has the effect of bending the light rays or actually it just moves them towards each other, so that they cross at a point, which ends up flipping the image over and turning it backwards.

I: And what happens without the lens?

S: Without the lens the rays just follow a normal straight path.

FIGURE 17

I: Suppose I were to take the lens away and put it on the table, leaving the light bulb and the screen exactly where they are. Would anything change on the screen?

S: I think it would disappear. I don't think you'd be able to see that anymore.

I: And how are you thinking there?

S: Well its just a light. You have a light. It would just be like a regular, ...no it wouldn't. It would either disappear or if it was on there it would not be upside down. I think it woud disappear.

I: Well what seems to be your confusion? You've given two alternatives. Do you have more confidence in the fact that it will disappear or are you unsure?

S: Maybe it would stay on there but it would be say like shining a flashlight. That's what I'm not sure of. Maybe, like with a flashlight, it seems like all the light is projected forward in a straight beam. But with that I'm not sure if it would go forward or if its just kinda going to spread around the light. But I think it would be on there, cause if its projected through the lens, even if you took the lens away, it would still have to be projected forward...For that (image) to be up there right now, that little lamp or whatever it is has got to be shining light beams through this lens that turn it upside down in here. But if you take the lens away then I think it would just shine straight ahead and the thing instead of being upside down would be right side up and it probably wouldn't be larger. It wouldn't be as large as it is there now, I don't think.

FIGURE 18

INTERVIEW DATA SUMMARY

LENS TASK: If lens were removed, what would you see on screen?

	PRE (N=[illegible])	POST (N=22)
No image (correct)	37%	50%
Erect image	58%	41%
Unsure	5%	9%

FIGURE 19

1. OKAY, THE IMAGE—WHAT HAPPENS IS THAT THE IMAGE OF THE CROSS COMES INTO THE LENS AS WE SEE IT, IS TURNED UPSIDE DOWN, AND THEN COMES OUT. SO IF YOU PUT THE COVER BETWEEN THE LIGHT SOURCE AND THE LENS, IT HASN'T HAD TIME TO TURN UPSIDE DOWN YET, SO WHAT APPEARS AS THE TOP OF THE LIGHT SOURCE IS THE BOTTOM OF THE IMAGE THAT YOU SEE, SO THEREFORE YOU WON'T SEE THE BOTTOM. LIKEWISE, IF YOU PUT THE COVER ON THE TOP HALF OF THE LENS AGAIN, ONLY THIS TIME IN BETWEEN YOUR IMAGE AND THE LENS, WHAT YOU'RE ESSENTIALLY COVERING IS THE BOTTOM HALF OF THE CROSS, BECAUSE IT'S BEEN TURNED AROUND.

FIGURE 22

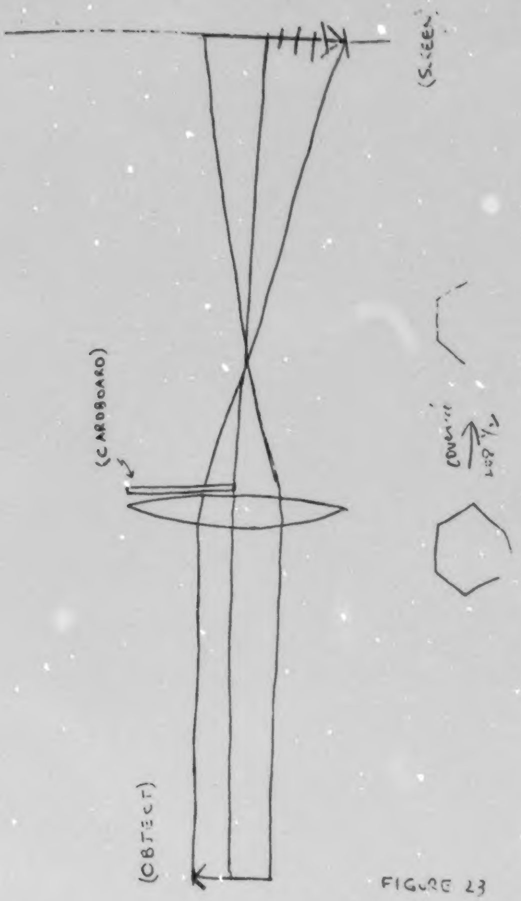
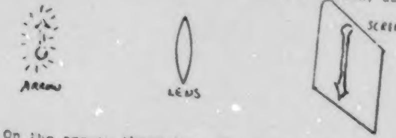


FIGURE 23

EXAMINATION DATA SUMMARY

(N=170)

In an otherwise darkened room there is a set-up consisting of an illuminated arrow, a lens, and a screen, as shown below.



On the screen there is a clear, inverted, and enlarged image of the arrow. Assume that after each question the set-up is returned to the initial situation described above.

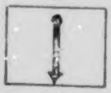
Suppose the lens is removed completely, leaving just the illuminated arrow and the screen. Which of the following sketches shows what you will see on the screen?

A

[No image at all]

58% *

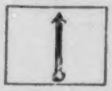
B



[Essentially the same inverted image, perhaps somewhat fuzzier]

1%

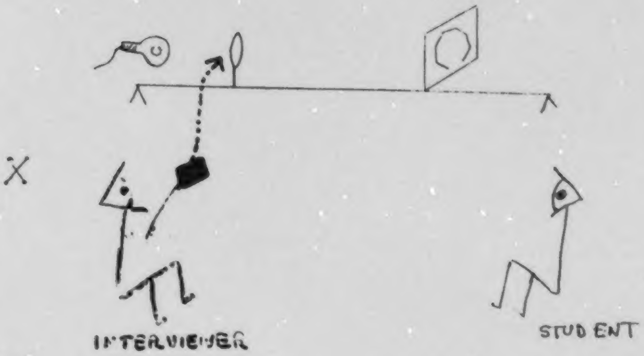
C



[Erect image, perhaps somewhat fuzzier]

41%

FIGURE 20

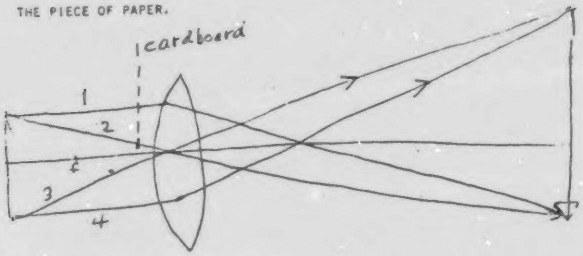


"SUPPOSE I WERE TO COVER THE TOP HALF OF THE LENS, LEAVING THE BOTTOM HALF UNCOVERED. WOULD ANYTHING CHANGE?"

FIGURE 21

SUPPOSE I BROUGHT THE CARDBOARD OVER AND I COVERED THE UPPER HALF OF THE LENS LEAVING THE LOWER HALF UNCOVERED. IF I WERE TO DO THAT WOULD ANYTHING CHANGE?

I FEEL, I KNOW THAT SOMETHING WOULD CHANGE. I'M GOING TO USE THE PIECE OF PAPER.



(LONG PAUSE). I FEEL THAT IF YOU COVERED UP THE TOP PART OF THE LENS THE BOTTOM PART OF THE IMAGE WOULD DISAPPEAR. OK. IN THE RAY DIAGRAM HERE, THE TIP OF THE ARROW IN MY DIAGRAM REPRESENTS I GUESS THE TOP OF THE U. AND SO WHEN FOLLOWING THE FIRST RAY STRAIGHT TO THE LENS, PARALLEL TO THE AXIS, IT WOULD GO THROUGH THE FOCUS. AND SO THE FIRST RAY, MARKED 1 WOULD GO PARALLEL TO THE AXIS BE BENT THROUGH THE FOCUS ON THE OTHER SIDE AND CONTINUE GOING ON IN THAT DIRECTION. AND THE OTHER RAY TOO, GOING STRAIGHT THROUGH THE MIDDLE OF THE LENS WOULD NOT BE BENT BUT WOULD CONTINUE GOING STRAIGHT AND WOULD HIT, WOULD INTERSECT RAY #1. I GUESS AT SOME POINT NEAR THE END OF THE PAPER. AND THAT WOULD CORRESPOND TO THE TOP OF THE IMAGE WHICH IS INVERTED. THE BOTTOM DOES EXACTLY THE OPPOSITE.

FIGURE 24

THE RAY 3 GOES THROUGH THE MIDDLE ALL THE WAY THROUGH TO NEARLY THE TOP OF THE PAGE AND THEN 4 GOES PARALLEL TO THE AXIS, GOES THROUGH THE FOCUS, AND AT SOME POINT INTERSECTS, I GUESS HERE SOMEWHERE, RAY 3 AND FORMS THE TOP PART OR WHAT CORRESPONDS TO THE TOP PART OF THE IMAGE. NOW IF YOU BLOCK OFF THE TOP PART OF THE LENS THAT WOULD BLOCK OFF RAYS 1 AND 2 FROM GETTING THROUGH SO THE BOTTOM OF THE IMAGE WOULD BE BLOCKED. THE BOTTOM PART OF THE OBJECT WHICH CORRESPONDS TO THE UPPER PART OF THE IMAGE WOULD STILL BE THERE.

HOW CONFIDENT ARE YOU IN YOUR PREDICTION?

FAIRLY CONFIDENT.

FIGURE 24a

INTERVIEW DATA SUMMARY

LENS TASK: IF UPPER HALF OF LENS WERE COVERED, WHAT WOULD YOU SEE ON SCREEN?

	PRE (N=36)	POST (N=29)
COMPLETE IMAGE (CORRECT)	0%	21%
HALF OF IMAGE	94%	69%
OTHER	6%	10%

FIGURE 25

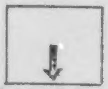
Suppose a large piece of cardboard is used to cover the upper half of the lens. [The cardboard touches the lens on the side closest to the screen.] The bottom half of the lens is not covered. Which sketch shows what you then will see on the screen.

A

[Top half of the image]

49%

B



[bottom half of the image]

23%

C

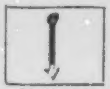


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FIGURE 26

The Effects of Misconceptions of Speed and Time on the Solution of Speed Problems

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This paper describes a study in which the analysis of students' solutions of speed problmes yielded a hierarchy of six solution models, from which we could infer the underlying knowledge structures. We studied the conceptual framework that includes the time and speed concepts, and the relationship among speed, time and distance in linear nonaccelarated motion.

The main purpose of the study was to find out what are the solution strategies that high school students employ to solve speed problems and to characterize their underlying knowledge structures.

1. The Methodology

The Test

The test included the two following problems in whose statements distance magnitude is either present or absent.

Problem 1. "Two cars start from city A. They go to city B, and return without delay to city A. The distance between the cities is 120 km. Car 1 goes to city B at the speed of 30 km/h and back at 50km/h, and Car 2 goes both ways at the speed of 40 km/h. Which car returned first to city A?"

Problem 2. "Two cars start from city A. They go to city B, and return without delay to city A. Car 1 goes to city B at the speed of 30 km/h and back at 50km/h, and Car 2 goes both ways at the speed of 40km/h. Which car returned firs. to city A?"

The student's answer included three parts: 1. a check of one of the following four possible answers: Car 1; Car 2; together; and insufficient information; 2. justification of the answer by an explicit computation; and 3. explanation (either mathematical or verbal) of the answer and computation.

The test instructions explicitly required the student to explain the answer and the written comutation in any preferred mode. This was done in order (1) to make explicit student solution and expalnation of the mathematical treatment, (2) to minimize the need to infer the solution processes solely from the written computation, (3) to explicate the student's underlying knowledge structures, (4) to enhance the analyzability of the responses, (5) to motivate the student to do her/his best on the test, (6) to ensure that the solutions reflect the student's highest competence level, and (7) to make the students reflect on their solutions and recover or modify incorrect ones. To achieve the last objective and to tell the student to pay attention to the difference between the two problems we explicitly hinted at it in the following way: In the tests where the problem with distance magnitude absent was first, after the solution of the second problem the following instruction appeared: "If you want to reconsider and/or change the solution to the previous problem please do here".

Cognitive analysis of these problems shows that they share the following features that render them potent of eliciting a variety of solutions from the students: (a) each of them involves a relatively simple physical situation, i.e., three variables and a single physical relationship, (b) their solution cannot be attained by manipulation of the given data and requires the computation and comparison of certain mediating variables (like time, distances gap, or weighted average speed), (c) their solution requires the use of certain mathematical procedures, that distinguish local (unidirectional) from global (bidirectional) elements and aspects. The two problems differ substantially on two related issues that result from the presence or absence of the distance magnitude: Their structures are different, a fact which may necessitate the use of different solution strategies.

It should be emphasized that problems with distance magnitude present and problems similar to them were practiced in mathematics classes. Problems in which either the distance magnitude was not given or the introduction of auxiliary variables (unknowns that are not necessarily solved for) was required were very rarely dealt with in mathematics classes and textbooks.

The Analysis

The following analysis was employed to the students' written solutions and explanations. First we classified the solutions into 29 nonoverlapping *solution types* according to their mathematical procedures and explanations; these solution types were then grouped into 12 *submodels* according to the nature of the quantities that were computed and compared; we then determined the levels of *physical representation* and *mathematical modeling* (which are explained below) for each submodel; these submodels were grouped according to their levels of physical representation and mathematical modeling into 6 *solution models*, four of which are incorrect. The solution models were arranged in a *hierarchy* according to their combined levels of the physical representation and mathematical modeling. This hierarchy reflects the correctness of the solution obtained by each model, i.e, the higher the model in the hierarchy the more elements of correct solutions it comprises.

The physical representation is an extension and refinement of Simon and Simon's (1978) two-level "physical intuition". Ours deals with the ways in which the solution treats the physical referents of the concepts distance, speed, and time, the rules relating them, and the crucial distinction between the local and global aspects of the situation.

The mathematical modeling is the mathematical method that was used to represent and manipulate the concepts, their features, and their relationships.

We have analysed the solutions under the working hypothesis that the physical representation and the mathematical modeling have three levels each. The levels of physical representation are: *None*: The solution lacks any physical referents. *Intuitive, or partial*: The solution includes incorrect physical referents, includes some but not all of the correct physical referents, or does not distinguish local from global relationships and considerations. *Complete*: The solution includes the relevant physical referents and makes a clear distinction between local and global relatonships and considerations.

The levels of the mathematical modeling are: None: The solution either does not include any symbols or uses them occasionally, does not use any quantitative method, or does not formulate algebraically the two-concept or three-concept relationship. Intuitive, or partial: The solution includes symbols, and employs either a qualitative or a quantitative mathematical method that is incorrect, based on misinterpretation of the mathematical symbolism, or incorrectly/inadequately coordinates local and global formulas. Formal: The solution uses a correct mathematical method that correctly coordinates local and global formulas.

The underlying knowledge structures can be characterized by the nature of these dimensions that are included in each solution model. The two following sections describe these issues, and the third section describes the inferred knowledge structures.

2. The Hierarchy of Solution Models

The solution models is depicted in Figure 1, and the following sections describe them in detail.

INSERT FIGURE 1 ABOUT HERE

The solution models share several features: They derive for each car or direction computed quantities from the data. They obtain compared quantities from either the data or the computed quantities. They compare the compared quantities, and provide an answer that is based on the outcome of the comparison. The solution models differ substantially in the nature of these quantities, in the use of the relationship between distance, speed, and time, and in the comparison process.

Model 1: Formal

Model 1 includes derivation of compared quantities that are either (i) for each car the total time that is the sum of the partial times, or (ii) for the car that was slower on the way to city B: either the time that it needs to close the distances gap between the cars, or the speed that it needs to catch the other car on the way back.

Model 1 comprises two submodels that differ in their relation to the taught procedures.

Model 1a (Standard solution): Computation for each car of the total time as the sum of its two underctional times. The latter are computed by the formula t=S/v or its equivalents. The total time was a global quantity and the underctional times are obtained from local quantities by correct local use of the three-concept relationship.

Model 1b (Non-standard solutions): This model comprises a variety of original (untaught) procedures that are apparently worked out by the more able students. It includes the explicit derivation by local use of the formula t=S/v of (i) the average speed for each car, (ii) the distances gaps between the cars in either one or two directions, and/or (iii) the time needed for the car that was slower on the way to city B to close the distances gap on the way back. The average speeds of the two cars, the time, or the speed needed for the lagging behind car to pass the leading car are compared with the time needed for the leading car to return to city A, or with the actual speed of the lagging behind car. The answer is: The faster car on the way to city B returned first to city A if (i) its average speed was greater than that of the other car, (ii) the time needed for the car that was slower on the way to city B to return from city B is greater than the time that is needed for the leading car to traverse the remaining distance to city A, or (iii) the needed speed for the lagging behind car is smaller than its actual speed. The locally computed quantities are derived from the local quantities by correctly using the three-concept relationship, and the compared quantities (either local or global) are obtained from the computed quantities by correctly using the three-concept relationship.

Model 1 has *complete* physical representation because *a*. the physical aspects of the situation, the concepts, and their relationship are recognized, explicitly mentioned and fully considered, and *b*. local and global aspects are clearly distinguished.

Model 1 has *formal* mathematical modeling because *a*. the concepts and their relationship are explicitly symbolized and properly used, *b*. the appropriate mathematical methods are correctly employed.

Model 2: Intuitive

Model 2 includes derivation for each car of two computed quantities that are the unidirectional times. These times are added to yield for each car a compared quantity of total time. The computed quantities are derived by implicitly using the formula t=S/v, or its equivalents, locally. The total time is derived by the correct combination (addition) of the local quantities. The comparison is purely numerical and makes no reference to any two-concept or three-concept relationship. No non-standard solutions are obtained in this model, which is used to solve problems in which distance magnitude is present. It is also used when distance magnitude is absent and a specific number is introduced for it.

Model 2 has *complete* physical representation because *a*. the physical aspects of the situation, of the concepts, and of their relationship are recognized, explicitly mentioned, and fully considered, and *b*. local and global aspects are clearly distinguished.

Model 2 has *intuitive* mathematical modeling because *a*. symbols are occasionally and inconsistently used, *b*. formulas are neither mentioned nor explicitly used, and *c*. the correct solutions are obtained by explicit arithmetic expressions that are obtained by implicitly using the formula t=S/v.

Model 3: Rote

Model 3 includes manipulation of the given numbers to derive for each car one or two computed quantities that were a "total speed" and/or a "total distance". These quantities are presumably substituted in the unmentioned formula t=S/v, to yield for each car a compared quantity of "total time". The "total times" are compared and the answer is: The car with the smaller time returned first to city A. The mediating variable time is derived from two global quantities by using the three-concept relationship. The computed and compared quantities are global quantities that are obtained as invalid combinations of global ones.

Model 3 has *intuitive* physical representation because *a*. speed is conceived of as an extensive quantity, *b*. the three-concept relationship is explicitly considered but incorrectly treated, *c*. comparisons are explicitly based on time, and *d*. local and global aspects are recognized but are confused.

Model 3 has *intuitive* mathematical modeling because *a*. symbols and formulas are occasionally used and units are correctly assigned to quantities, *b*. arithmetical expressions are used to represent the relationship between distance, speed, and time but the formula t=S/v (or any of its equivalents) is neither stated explicitly nor are the given numerical values substituted in it, and *c*. incorrect global quantities are used in the implicitly underlying formula t=S/v.

Model 4: Compensation

Model 4 includes manipulation of the given numbers to derive for each direction computed quantities that are either "distances gaps", "times gaps" or "speeds gaps" between the cars. Distance is identified with speed by explicitly assuming that the cars went in each direction for 1 hour. None of the needed mediating variables is explicitly produced but time and distnace are considered inversely or directly

related (although not strictly proportional) to speed differences. The derivation of the computed quantities and the comparison of the compared quantities are based on implicit reference to a two-concept relationship. The computed quantities are local ones which are derived from local quantities by invalid procedures.

Model 4 comprises three submodels that differ in the sort of the computed gap.

Model 4a: Assessment of "distances gaps" or "times gaps" between the cars in each direction as either equal or proportional to the speed differences with distance units. Occasional and implicit qualitative reference to the distance between the cities is made, mainly in the comparison.

Model 4b: Derivation of "speeds gaps" between the cars in each direction as the speed difference with either distance or speed units.

Model 4c: Assessment of "semi-quantitative speeds gaps" between the cars in each direction as the order relation of the speeds differnces between the two cars. These gaps are compared by implicitly considering their sizes (without using numbers or units) and the answer is: The car that on the way back is "more faster" than it was "more slower" on the way to city B returned first to city A.

Model 4 has *intuitive* physical representation because *a*. the speed, distance, and time concepts are imprecise and vague (for instance, the units are used interchangeably; no conflict is recognized when the distance between the cities is assumed to be equal to the different speeds of the two cars; distance was identified with speed without realizing the implication that t=1 hour; speeds are manipulated as extensive quantities), b. the need to compensate in time or distance for speed differences is recognized but inappropriately treated (for instance, speeds, times, and distance gaps are introduced), and c. a two-concept relationship is implicitly considered although it is neither stated nor used.

Model 4 has intuitive mathematical modeling because a. symbols and formulas are neither mentioned nor used, b. two-concept relationships, despite being implicitly considered, are not formulated quantitatively, and c. arithmetical operations are performed that are incompatible with the correct mathematical procedures.

Model 5: Concrete

Model 5 includes manipulation of the given numbers to obtain for each car a computed quantity that is either a "typical speed", a "total distance" or a "total time". The answer, which implicitly uses a two-concept rule and is bases on the comparison of the two computed quantities, is: The car with the greater "typical speed" or "total distance" or with the smaller "total time" returned first to city A. None of the needed mediating variables is produced and the computed quantities are global that were obtained by direct invalid manipulations of the data. These manipulations are based on neither the three-concept nor on a two-concept relationship and the computed quantities serve as the compared quantities.

Model 5 comprises four submodels that differ in their computed quantity.

Model 5a: Computation for each car of a "total speed" that is either the sum or difference (for the car with two different speeds) of the given speeds with a speed unit (km/h).

Model 5b: Computation for each car of an "average speed" that is the unweighted average of its given speeds with a speed unit (km/h).

Model 5c: Computation for each car of a "total distance" that is the sum of the given speeds, or a "distances gap" that is a linear combination of the speeds with a length unit (km).

Model 5d: Computation for each car of a "total time" that is the sum of the given speeds with a time unit (hour).

Model 5 lacks physical representation because a. the distance between the two cities is occasionally mentioned but never used, b. the three-concept relationship is not mentioned and two-concept relationships are either explicitly or implicitly used (for instance, distance is identified with speed and time is inversely related to speed), c. the distance, speed and time concepts are imprecise and vague (for instance, speeds which are intensive quantities (Piaget, 1952), are manipulated as extensive quantities, d. the physical units are used interchangeably, and e. global and local quantities are not distinguished.

Model 5 has intuitive mathematical modeling because a. symbols and formulas are neither mentioned nor used, b. time and distance are identified with speed by assigning units rather than assuming that the time was 1 hour, and c. inferences are either based on chance numerical relationships rather than on mathematical argumentation, or they are justified by invalid mathematical methods (for instance, a decision is based on the difference between the sum of the speeds of Car 2 and the speed of Car 1).

Model 6: Confusion

Model 6 includes manipulation of the given numbers (speeds and distance) according to nonexistent and idiosyncratic mathematical procedures and obtains for each car a dimensionless (without units) "number". The two "numbers" are compared, and the answer is: The car with the smaller "number" returned first to city A. These "numbers" were interpreted as "total times" according to their role in the answer. None of the mediating variables is produced, no relationship seems to underlie the data manipulation, and the comparison implicitly considered the two-concept relation "time is inversely related to speed".

Model 6 comprises two submodels that differ in the apparently intended meaningfulness of the computed quantity.

Model 6a: Manipulation of the data so to obtain a "number" that apparently makes sense to the student. This "number" was a global quantity that was obtained as an invalid combination of local quantities.

Model 6b: Manipulation of the data without any apparent attempt to obtain a meaningful "number". This "number" was a global quantity that was obtained as an invalid combination of local quantities.

Model 6 *lacks* physical representation because *a*. no physical features of the situation are represented in the solution (for instance, the time is assumed to be the same for both cars, the motion direction is not considered, and different distances are used in each direction, and *b*. the physical relationship between distance, time and speed is either not mentioned or is confused (for instance, the units are mixed up, and speed is identified with time).

Model 6 also *lacks* mathematical modeling because *a*. mathematical symbols (variables) are only occasionally used, *b*. no formulas are mentioned, and *c*. nonexistent and invalid mathematical procedures are used (for instance, the time of one car is multiplied by the reciprocal of the time of the other car).

In addition to these six models we identified the following solution procedures: (i) those utilizing only partial information which could not be determined to result from misunderstatnding or from inattentional performance (e.g., considered motion in only one direction or used only one of two speeds of one car) and (ii) procedures which are unclassifiable since they do not conform to any of the solution models. The latter subcategory comprises 3.9% of the total solution procedures and confirms the good applicability and the high exhaustiveness of the hierarchical system.

Rules comprise a major part of conceptual frameworks so in the next section we clarify their roles in the solution of speed problems by explicating and elaborating on their nature and use in each solution model.

3. The Nature of Rules and Their Application

The use of rules is characterized by what rules were used, for what purpose, and when in the solution were they applied.

Figure 2 depicts the three parts of the solution processes.

INSERT FIGURE 2 ABOUT HERE

This analysis shows that the solution models differ in the three major parts of the solution:

a) The derivation of the computed quantity: Models 1 and 2 compute the local computed quantities by using the local formula $t=S/v$, which is the full local relationship. Model 3 derives the global computed quantities by procedures that combine local speeds and distances incorrectly without uing any relationsip. Models 4-6 derive the global computed quantities by procedures that combine local speeds incorrectly.

b) The derivation of the compared quantities: Models 1 and 2 derive the global compared quantities by correctly combining the local computed quantities. Model 3 derives the global compared quantities by substituting the global computed quantities in the formula $t=S/v$. Models 4-6 use the computed quantities as the compared quantities.

c) The comparison: Models 1-3 make a direct (numerical) comparison of the two compared quantities without using any relationship. Models 4-6 compare these quantities by implicitly referring to a partial relationship.

We interpret the use of the partial relationship of speed and time not as a shortcut that is achieved by implicitly using the full relationship. Rather, it is produced by a data-driven schema resulting from a persistent physically immature conception that relates only two of the three concepts.

This interpretation of the results is supported by the following evidence: (1) The incorrect procedures were applied by many students despite the algebraic context and, therefore, reflect the "real" underlying conceptual knowledge. (2) Due to the highly abstract nature of the time concept it is the most difficult to acquire, and the last both to develop and to be integrated with the other two (e.g., Fraisse, 1963, 1982; Friedman, 1982; Richards, 1982; Siegler and Richards, 1979; Wilkening, 1981,1982). This is also the case with our students, the majority of whom could not integrate the three concepts at the symbolic level. (3) Our students had great difficulties to conceive of the time as a mediating variable. (4) This finding is parallel to those reported by Champagne, Klopfer, and Anderson (1980) and DiSessa (1982).

4. The Underlying Knowledge Structures

The former analyses enabled us to characterize the knowledge structures that probably led to the use of the solutions models. These models prevail not only the performance of novices but were abundant also in grade 11, when mastery of the official models are assumed to be fully achieved. The knowledge structures that are evident from the employed models have the following features:

1. Features and terms that appear in the problem statement are more important than conceptual relationships among the concepts, and lead to data-driven schemas.

2. The knowledge structures do not include the concept of mediating variables and coordination. Thus the main perceptual data i.e., the speeds, are the major (sometimes the sole) determinant of the problem structure and solution; the physical and mathematical dimensions are not coordinated in the problem representation; the distance in both directions is not coordinated with speed and time; and the (equal) distances travelled by both cars are only partly coordinated via the speed differences.

3. The concepts and their features do not have their scientific mature meanings. Speed is conceived of as an extensive rather than intensive quantity i.e., as amenable to numerical operations (like addition and division) which in this case are mathematically invalid. (This conception of speed apparently has not arisen from the valid vector addition of speeds.)

4. The knowledge structures do not always contain the three-concept relationship among distance, speed, and time. Rather, they consist of early developed two-concept relationships characteristic to young children of 5 to 10 years of age (e.g., Friedman, 1982; Wilkening, 1981). These non-metric or semi-metric relationships are the inverse relation of time and speed, and the direct relation of time and distance, and of distance and speed or speed differences. They do not reflect strict proportionality but only some kind of functional relation. Distance is not coordinated with speed and time through the three-concept relationship.

5. The knowledge structures sometimes do not include the distinction between local and global concepts and relationship, and in other cases these are used interchangeably and remain uncoordinated.

6. Time is not included in the knowledge structures regarding motion. It is neither conceived of in general nor considered a necessary mediating variable.

7. These knowledge structures are deeply rooted in early conceptions, are very stable, and are relatively unaffected by instruction.

5. Educational Implications

Our methodology for the analysis of the solutions and their explanations, which is more abstract than protocol analysis, proved very fruitful in bringing about a very fine-detailed and precise picture of solution strategies and knowledge structures. It can be used to study conceptual frameworks and knowledge structures of other domains via the employed solution models. It can also be used to devise individual interviews with students on the basis of their actual solution processes. We see potential diagnostic uses also for instructional designers and classroom teachers.

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Model	Main Feature	Level of Physical Representation	Level of Mathematical Modeling	Submodel	Description	Relative Frequency (Percent) of Use in Grades		
						9	10	11
1	Formal	Complete	Formal	1a	Standard: Comparison of total times of the cars, that were derived by using the formula $t = S/v$ (or its equivalent) unidirectionally	10.0	20.9	17.0
				1b	Nonstandard: Comparison of average speeds of the cars or the times needed to close the distances gap between the cars, or the needed and actual speeds of a car	1.4	0	8
2	Intuitive	Complete	Intuitive		Comparison of total times of the cars that were derived by implicitly using the formula $t = S/v$ unidirectionally	18.6	11.6	20.0
3	Rote	Intuitive	Intuitive		Comparison of "total times" of the cars, that were derived by substitution of incorrect overall S or V in the formula $T = S/V$	4.5	7.7	4.1
4	Compensation	Intuitive	Intuitive	4a	Comparison of partial "time gaps", or "distance gaps" between the cars in every direction, that were inversely or directly related to the speeds differences of the cars	5.4	2.9	1.6
				4b	Comparison of partial "speed gaps" between the cars in every direction, that were the speed differences between the cars	6.7	4.7	3.3
				4c	Semi-quantitative comparison of order relations between speed differences of the cars in every direction	1.8	2.0	1.1
5	Concrete	Intuitive	None	5a	Comparison of "total speeds" of the cars, that were computed as the sum or difference of speeds	16.5	10.7	9.2
				5b	Comparison of "average speeds" of the cars, that were computed as unweighted average of speeds	5.4	12.4	12.2
				5c	Comparison of "total distances" of the cars, that were computed as the sum of speeds (distance identified with speed)	5	0	0
				5d	Comparison of "total times" of the cars, that were computed as the sum of speeds (time identified with speed)	4	0	0
6	Confusion	None	None	6a	Comparison of "total times" of the cars, that were derived from nonsense but "apparently meaningful" manipulation of the data	1.0	1.4	4
				6b	Comparison of "total times" of the cars, that were derived from nonsense manipulation of the data	2.2	6	0
P	Partial				Uses only partial information	13.1	15.2	16.3
U	Unclassifiable				Cannot be classified into any of the models	12.9	10.1	12.6

Note. Percents were calculated within each grade level.

Figure 1. Solution models with their relative frequencies of use

Model	Nature and Derivation of Computed Quantity	Nature and Derivation of Compared Quantity	Nature of Comparison
1	Local, calculated by local formula that is based on three concept relationship	Global, calculated by numerical combination of local quantities	Direct, numeric
2	Local, calculated by local formula that is based on three concept relationship	Global, calculated by numerical combination of local quantities	Direct, numeric
3	"Global", obtained by numerical incorrect calculation without using any formula or relationship	"Global", calculated by using a "global" formula that was based on three concept relationship	Direct, numeric
4	"Global", obtained by numerical incorrect calculation without using any formula or relationship		Indirect, based on implicit two concept relationship
5	"Global", obtained by numerical incorrect calculation without using any formula or relationship		Indirect, based on implicit two concept relationship
6	"Global", obtained by numerical incorrect calculation without using any formula or relationship		Indirect, based on implicit two concept relationship

Figure 2. Nature and derivation of quantities in solution phases of solution models

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MISCONCEPTIONS IN PHYSICS AMONGST NIGERIAN SECONDARY SCHOOL STUDENTS

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Introduction

In recent years, some misconceptions in physics have been detected amongst candidates taking the West African School Certificate (WASC) Examinations in Nigeria. Despite the practice of the West African Examinations Council (WAEC) sending the Chief Examiner's report to schools, with the aim of making teachers become aware of popular mistakes in the candidates scripts, the mistakes which arise from lack of proper understanding of some physics concepts are still repeated.

A common cause of these misconceptions may arise from the teaching methodology in schools. Most schools are not lucky enough to have adequate number of physics teachers; the few that are available often have to cope with a large number of teaching periods and students. Consequently, teaching is accomplished through talk and chalk most of the time, resulting in the memorisation of facts for the purpose of passing tests. When such tests involve questions relating to the higher cognitive levels of educational objectives (Bloom et al, 1971), the lack of understanding of the relevant concepts by the students becomes obvious. But in a guided discovery method of teaching, students experience the effects of physics concepts through experimentation, look for a trend in their observations and make reasonable conclusions. In the process of doing this, they try to explain their observations and get to understand the concepts properly.

The misconceptions do cover a number of concepts in physics. Apart from the misconceptions listed in Helm (1980) some common mistakes are found in other areas of physics. For instance, many candidates do not appear to understand uniform motion. In some textbooks the impression is given that uniform motion involves only motion with constant acceleration. The case of a body moving in such a way that its velocity is constant is described in such books as "a body moving with constant velocity" as if it were not moving uniformly. The misunderstanding of this special case of a uniform motion leads to a misconception about the more special case of zero velocity.

In waves, the distinction between transverse and longitudinal waves is often improperly stated because of the misconception about the response of a medium to a disturbance passing through it. Instead of talking about the direction of vibration of the particles of a medium relative to the direction of wave motion, candidates often talk of the waves vibrating.

Having found a large similarity between these misconceptions and those reported by Helm (1980) as common amongst South African students, it was desirable to investigate the spread of these misconceptions in physics amongst secondary school students in Nigeria. In the light of such findings, possible causes and solutions may be suggested.

Method:

The data for this study were obtained from a test administered to form five students in eight secondary schools in Nigeria.

Four of the schools were Federal Government Colleges while the other four were established State owned Secondary Schools. Two schools from each category of schools were chosen from the north and south of the country. This also gave a total of four schools from each part of the country. The performance of these schools at the 1980 and 1981 WASC examinations was also considered in selecting these schools. In terms of facilities, all the schools were about equally equipped and had adequate staff to handle science teaching. Students in these schools were therefore expected to perform at very high level. Of the 20 multiple choice items on physics concepts used for the test 12 were modified items of Helm (1980). The stem of these items were the same as those used by Helm (1980) but more options were now provided to comply with the WAEC format of five options in multiple test questions. Since the published version of Helm's test did not contain all the options he used, these had to be provided in this investigation. The questions concerned selected topics covering motion, conservation principles, waves, fields and quanta; which form the content of a WAEC 'O' level syllabus in physics. The options provided for each question contained some known or suspected misconceptions used as distracters in conformity with earlier techniques used by Doran (1972) and Johnstone and Mughol (1976).

Realising that the form five students may not have covered all the topics at the time the test was administered, they were told to skip any questions relating to areas of physics not yet treated in class. By the general practice in most secondary schools in Nigeria, electricity and magnetism brings up the rear in preparation for the WASC examinations in physics in May/June of every year.

In other to validate the questions, especially those outside the published test (Helm, 1980), some physics teachers and physics educationists were requested to check the questions in the test. On the basis of their reactions, the test items were finalised and administered on the students. As a way of investigating possible causes of misconceptions, physics teachers in the schools where the test was administered also took the test and were interviewed. The textbooks used in schools were also examined.

Results:

Table 1 shows the frequency of selection of particular options by both the students and their teachers for all the 20 questions. The correct options are shown in the column for key. On a number of questions (1, 4, 7-8, 13, 15, 17-18) less than 20% of the students selected the correct options; in particular questions 1 and 8 had less than 10% of the students able to select the right answer. In these cases, particular distracters were very popular with the students. In 7 questions (3, 5, 9, 11-12, 19-20) more than 50% of the students selected the correct options and in particular questions 9 and 20 were very favourably answered by over 80% of the students.

As for the teachers, all of them chose the correct options in questions 9, 11, 12, 19; majority of them selected the correct options in many of the questions while none of them selected the correct options in questions 7 and 15. The performance of the teachers in some of the questions follows about the same trend as that of the students. For example, only 30% or less of the teachers chose the correct options for questions 2, 4, 8, 14 and 17-18.

In table 2, the combined frequency distribution of the students' responses is shown. In order to investigate any statistical difference between the performances of the students from the Established State Schools (ESS) and the Federal Government Colleges (FGC), the Chi-square statistic was calculated. The table shows that the grouping of the students into State and Federal Schools is not a significant factor influencing their misconceptions in physics ($x^2 = 5.3$, df = 1 as compared to a x^2-value of 6.64 required for significance at the 0.01 level).

Using the average score of students on each question as our variable, the overall mean score by the ESS students was compared with the score by the FGC Students, utilising the t-statistic. A similar comparison was made for the calculated mean score from Helm (1980) results and the mean score of the present study. The calculated t-values in Table 3 are 0.424 and 1.522 respectively, which are less than the value of 2.704 required for significance at the 0.01 level. This has further confirmed the non-statistical difference between the performances of the two groups of students in the test. It also suggests that the misconceptions in physics amongst the students in this study and that of Helm (1980) are insignificantly different.

TABLE 1: FREQUENCY DISTRIBUTION OF RESPONSES TO QUESTIONS

Question	key	STUDENTS · N = 258					TEACHERS N = 10				
		A	B	C	D	E	A	B	C	D	E
1.	C	199	36	12	8	-	5	-	5	-	-
2.	A	72	124	15	20	26	2	3	-	-	5
3.	C	30	37	141	25	23	-	-	8	-	2
4.	E	71	18	63	60	37	2	-	3	2	3
5.	E	46	23	14	10	160	4	-	-	-	6
6.	A	55	36	36	106	11	6	2	2	-	-
7.	B	74	48	113	7	7	7	-	3	-	-
8.	E	158	47	20	15	18	5	2	-	-	3
9.	C	32	7	207	3	8	-	-	10	-	-
10.	C	99	34	63	13	31	2	-	8	-	-
11.	B	82	163	5	1	4	-	10	-	-	-
12.	B	23	157	11	19	42	-	10	-	-	-
13.	D	47	23	51	49	39	-	5	-	5	-
14.	A	66	27	33	28	41	3	7	-	-	-
15.	B	37	34	47	66	[illegible]	10	-	-	-	-
16.	D	71	31	27	82	10	2	-	-	8	-
17.	A	28	125	62	7	5	3	5	2	-	-
18.	D	30	16	72	32	71	2	6	-	2	-
19.	A	174	54	8	5	7	10	-	-	-	-
20.	D	16	12	-	220	5	-	2	-	8	-

The two groups of schools (ESS and FGC) have sample population of 129 students each. ESS indicates Established State Schools while FGC indicates Federal Government Colleges.

Scoring 1 for correct options and zero for the distracters, the overall mean score by the students is 7.04 out of 20, which gives an average performance score of 35.2%.

TABLE 2

COMBINED FREQUENCY DISTRIBUTIONS OF RESPONSES

	Right	Wrong	Total
ESS	949	1631	2580
FGC	869	1711	2580
Total	1818	3342	5160

$x^2=5.30$

df=1

Not significant at 0.01 level.

Here both omissions and selection of distracters are regarded as wrong responses while a selection of the correct option is taken as right.

TABLE 3

COMPARISON OF MEAN SCORES

	Mean Score	N	t
ESS	36.8%	129	0.424 Not significant
FGC	33.7%	129	
Helm's Study	25% *	460	1.522 Not significant
This Study	35.2%	258	

* Calculated from Helm's result.

Discussion:

This study has indicated a wide spread of some misconceptions in physics amongst selected secondary school students in Nigeria. These misconceptions do not depend on the type of school the students attend, given the same educational facilities in the schools. The teachers who teach these students seem to have similar misconceptions in some areas of physics. The main causes of these misconceptions in students can be traced to teachers and some available textbooks. These findings complement the report of Helm (1980) for students in South Africa.

Johnstone and Mughol (1976) reported three main causes of difficulty in physics concepts formation at secondary school level. These are teaching, normal language usage (which tend to confuse and undo teaching) and everyday experience of material world. Helm (1980) found the teachers as the major cause of misconceptions in physics amongst South African students, with textbooks and examination papers contributing their fair share. He further suggested that the misconceptions revealed a general mismatch between students' intelletual development and the demands made upon them by the content of their courses. But Bruner (1960) has pointed out that the child is ready to learn when the teacher is ready to teach; and argued further that any subject can be taught effectively in some intellectually honest form to any child at any stage of development. Although this is too much of a generalisation, the fact remains that teacher effectiveness in the class is very crucial in the formation of concepts by the students. His role in providing the right learning atmosphere and in guiding the students through their learning experiences underscores his importance in the educational development of the student. But as will be seen later in this paper, the physics teacher in Nigeria has problems which do not tend to make him utilise himself to the fullest. Instead of the mismatch suggested by Helm (1980) there is rather a mismatch between what the society demands of students and the provision made by the same society for the learning experiences of students in schools (Ivowi, 1982). A detailed observation of table 1 shows that students have performed fairly well in questions relating to waves and Quanta while they have done badly in questions relating to conservation principles, fields and motion.

Students think that when two objects move with the same acceleration, they necessarily will cover equal distance in equal interval of time. This is why more preferred the distracter C to the correct option E in question 4. They forgot that the story is not complete without a knowledge of their initial state (i.e. value of velocity). One could not correctly predict their journey without knowing their initial velocities. Both students and teachers failed to assess the situation correctly. Although majority of students and teachers selected the correct option in question 5, it is clear that a reasonable number of them refused to recognise zero velocity as a special case of uniform motion.

The misconceptions shown for questions 6, 7, 8 relating to conservation principles are similar to those reported by Helm (1980). Although performance was good generally in waves, there was evidence of confusion in the definition of the refractive index of a medium with respect to another medium.

The poor performance in questions relating to fields (electricity and magnetism) may be explained by the fact that formal teaching of this aspect of the syllabus had not progressed much when the test was taken. But the performance of the teachers especially in questions 14, 15 and 17 indicates lack of frequent revision of the relevant topics. But majority of the students attempted these questions and had no particular preference towards any correct option or distracter. It is possible that most of the selections arose from mere guess work although both teachers and students confirmed that students have read some of the topics on their own. The good performance in questions 19 and 20 may be due to majority of them doing chemistry. In question 20, it was obvious to the students that the photon was odd in the list provided. Since the photon is the quantum of electromagnetic radiation and can be considered as elementary particle, it would be reasonable to expect to find it in some atoms especially when it causes excitation of atoms. But this is beyond the level of the students and hence question 20 would be regarded as fair all the same.

The misconceptions revealed in this study, which find similar explanations in difficulties in understanding as stated by Helm (1980), indicate a number of observations. These observations also relate to an examination of physics textbooks in the country and to the interviews held with some teachers. They also indicate the directions for possible solutions to the problem of misconceptions in physics amongst students. The observations are as follows:

(i) Too many facts are given mostly in their general forms without much recourse to their applications. In questions 1 and 2, apart from the inability to identify the agents exerting forces on the different objects concerned, the known fact that forces always occur in pairs could not be applied to the given situation. Also the fact that tension is an example of a contact force could not be utilised in this question. In question 1, the fact that the gravitational pull on block A produces the tension in the string that is tied to block B ought to make students see block A as a very remote agent.

(ii) Many explanations of concepts are also given in general form without extra pains being taken to reduce such explanations to the language easily understood by the students. The dependence on the textbook explanations do not make things clearer to the students. As most explanations are not acceompained with demonstrations and adequate laboratory activities, there is still difficulty in the understanding of concepts.

(iii) Textbooks treat some topics rather superficially and with misplaced emphasis. Some good examples are the use and definition of constant velocity and uniform acceleration mentioned earlier on and the concept of e.m.f. Since students tend to depend so much on textbooks and formal notes given to them in class, the source of their limitations is obvious in this case.

(iv) There is evidence of inability to grasp definitions properly. This is because particular attention is not paid to the operating words in a given definition. This is the case with questions 8, 10, 11 and 15. Any statement close to the actual meaning of a physics concept is easily mistaken for the correct definition. Hence most students opted for the distracter A in question 8. The teachers' choice of the same distracter is indeed a case of carelessness.

(v) A serious problem facing physics teaching in Nigeria is the acute shortage of physics teachers. As a result, the few teachers around have a heavy work load and coupled with the inadequately equipped laboratories, there is a low teacher effectiveness in class.

(vi) The style of WASC examination papers had tended to encourage students to restrict themselves to the lower cognitive level of educational objectives. This has just begun to change with more analytical questions that require evidence of actual understanding being set.

Since most of the problems centre around teaching and textbooks, the solution appears to rest with the improvement of the teaching of physics in schools and of the instructional mateirals available to students. There is a great deal of work in the direction of improved textbook production, an example being the Nigerian Secondary Schools Science Project (NSSSP) Physics (CESAC, 1979 and 1980). As for teaching, three major problems have been identified (Ivowi, 1980) as personnel, equipment and curriculum. Articulated efforts have been made to spell out the philosophy, objectives and contents of the physics courses. Compared with the programmes in many developed countries, one is quite satisfied with these efforts. The equipment problem remains very real despite the efforts being made by educational authorities. The problem is even complicated by the astronominal population explosion in schools since 1979. An annual teacher education in-service-training programme had begun in 1975 for science teachers in pilot schools run by CESAC. The number of physics teachers sponsored every year to this vacation course is rather small (less than 30). But evidence exists of the usefulness of this course to physics teachers especially in the area of positive change in attitudes towards physics teaching in schools (Ivowi, 1980). If this and other vacation courses in physics are held for a much larger number of physics teachers regularly, some improvement in physics teaching can be achieved. In the final analysis students may have a better understanding of physics concepts.

Conclusion:

On the basis of the findings in this study it could be concluded that misconceptions in physics appear wide spread amongst secondary school students in Nigeria in about the same manner as they occur to students in Sough Africa. The inadequacy in human and material resources for the teaching of physics in schools could be minimized by a more articulated effort in in-service teacher education training programmes, textbook production and equipping physics laboratories.

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HOW SWEDISH PUPILS, AGE 12-15, UNDERSTAND LIGHT AND ITS PROPERTIES*)

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HISTORICAL BACKGROUND (Source: Ronchi, 1970)

Up till the seventeenth century the history of ideas about light is the history of how mankind gradually and painstakingly came to understand that light is a physical object that exists and propagates in space, apart from sources and effects. The decisive break-through was achieved by Kepler, who began his work "Ad Vitellionem Paralipomena" (1604) with the propositions:

I: Light has the property of flowing or of being emitted by its source towards a distant place.

II: From any point the flow of light takes place according to an infinite number of straight lines.

III: Light itself is capable of advancing to the infinite.

IV: The lines of these emissions are straight and are called rays.

There is every reason to regard Kepler's propositions with respect. They represent the culmination of 2000 years of mental extertion, which began in Ancient Greece.

The Greeks were deeply interested in understanding man and as vision is an important human faculty, they tried to answer the question: "What happens when we see an object?" During the fifth and fourth centuries B.C., in particular, keen discussions took place to clarify, among other things, the link between the eye and the object seen.

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*) This article summarizes a more detailed report included in the series of reports entitled "Elevperspektiv" (The pupil's perspective). This report, "Light and its properties", which is available both in Swedish and in English, describes answers to a greater number of problems than are mentioned in the article. In addition, interviews with 21 pupils are analysed and illustrated by examples. This report may be obtained from Björn Andersson, EKNA project, Department of Educational Research, P.O.Box 1010, S-431 26 Mölndal, Sweden.

Empedocles had the idea that objects emitted an "external fire", which reached the eye, by analogy with smoke, for instance, which reaches the nose, or sound, which reaches the ear. This elementary fire brought the shape and colour of the object with it. But this external flux was not sufficient to explain vision. From the interior to the exterior of the eye came an internal elementary fire, a kind of visual flux and met the external flux, giving rise to vision. In animals that see in the dark, the visual flux could pass outside the eye.

Another fundamental idea was to imagine a flux only from the exterior to the interior. The Atomists are representatives of this view. Thus, for example, Leucippus, a contemporary of Empedocles, considered that, as the soul could not come out and touch objects, then the objects must come right into the soul by passing through the sense organs. But the objects as such do not move. They must, therefore, emit something that represents them to the soul. Leucippus imagined a kind of image, called eidola, that detached itself from the surface of the object and conveyed properties, such as shape and colour, to the soul.

There was yet another contemporary explanation, namely that of a flux only from the interior to the exterior. This idea was put forward by the Pythagoreans. Archytas, for instance, thought that the act of seeing could be explained solely by the existence of an invisible fire, emitted by the eye, which revealed the colour and form of the object.

The Pythagoreans' model of the link between the object and eye was further developed by Euclid, whose great contribution to the development of optics was the concept of the ray. This concept made its appearance on the scene of history with the first postulate in Euclid's first optical work: "The rays emitted by the eye travel in straight lines." So it is a question of visual rays, the properties of which explain vision.

It is interesting to note that Euclid also introduced the concept of sun-ray. In a later work he reported, among other things, that it is possible to light a fire with the aid of a concave mirror held up towards the sun. In the proof of this it was discussed how rays sent out by the sun were reflected by a mirror. But these sun-rays never find their way into his logically constructed visual-ray optics.

The next act in the history of optics was staged in the Arabic sphere of culture. Concrete knowledge of the eye's anatomy led to the realization that something material must enter the eye and affect it in a physiological way.

Alhazen (965-1039) observed, for instance, that if we look at the sun, both directly and indirectly, in a mirror, our eyes hurt. He also observed that the eye is blinded if one looks at bright, white objects. He believed that this could not be explained by visual rays. Instead, it had to be rays of a material nature, which entered the eye from the exterior. This reasoning was then generalized to common objects. When these are struck by sunlight, they throw back this light in all directions. The light rays that enter the eyes give rise to vision.

This realization constituted a great advance and made it possible for Alhazen to formulate a new problem: How could the light rays which entered the eye convey the object's structure and form? Alhazen suggested a new idea. He assumed that for each point on the object there was an equivalent inside the eye in the form of a stimulated point. However, his proof, which was based on the idea that the light-sensitive part of the eye lay in the front half of the eye-ball, left many questions unanswered.

Alhazen was very much ahead of his time and was not even typical of the Islamic School of Science. He soon fell into oblivion. During the Middle Ages a return was made to the Classical writers, who were studied in a spirit of exaggerated awe and respect, and the link between object and eye still consisted of visual rays and floating images.

It was Johannes Kepler who took the decisive step and developed the principles of geometrical optics, giving them a clear and simple form that they are to a large extent still valid today.

Kepler returned to the ideas of Alhazen and developed them in his own way, without any side-glances at the Classical writers, who were still enjoying great popularity. Kepler's work decisively established the idea that light is a physical object, which propagates in space, apart from sources and effects.

In the continued development of optics colour phenomena came to play an important role. Kepler believed that colour was a property of the object and that light was colourless. He thought that when light passed through coloured plates of glass, or was reflected against surfaces, it extracted colour. It was left to Isaac Newton and others to make decisive contributions to the understanding of colour phenomena.

EARLIER INVESTIGATIONS

As early as 1903, Stanley Hall (quoted by Piaget, 1927) reported a spontaneous question by a five-year-old: "Papa, why don't our looks mix when they meet?" Hall also reports something one adult remembered from childhood: "I used also to wonder why it was one did not feel someone else's look, on the cheek for instance if they were looking at one's cheek."

Piaget himself (1927) describes some related ideas, in three excerpts from interviews. In his work "Understanding Causality", Piaget also describes three stidues that concern the way children understand light. (Piaget, 1974) The children interviewed were asked to explain how it is possible to see an image of an object in a mirror and how a circle of light can be made on a wall by a lamp. The interviews are desribed only very briefly. Piaget sums them up as follows:

"Despite the daily use of flashlights and the common idea of 'rays' of the sun or of sources of light, the understanding of the transmission of light is scarcely more precocious than that of heat. It is not until stage III (The formal operational stage beginning at 11-12 years of age according to Piaget) that the subject admits the existence of light 'between the machine and the round spot... I don't see it but I know it's there.'"

At the end of the 1970's a French project group for the development of science teaching, under the leadership of Professor G. Delacôte, carried out some interviews of pupils about their understanding of light and vision. Thiberghien et al. reported that pupils of 11 years of age do not generally use the model "Light is something that propagates in space" when they try to explain the formation of shadows and images. On the other hand, fourteen-year-olds show many signs of using this model. They say, for instance, that an object obstructs the light. Light cannot penetrate the object. Light bounces on the mirror. In answer to the question "In what part of the room is there light?", an 11-year-old may say "on the walls and ceiling". A 14-year-old, on the other hand, more often says "in the whole room".

Guesne (1978) interviewed 20 pupils of 14 about light and vision. The introductory question seems to have been "What is it that makes you see this object?" The pupil was asked to explain how he/she could see sources of light, both primary and secondary. Most of the pupils never mention any linking mechanism between the object and the eye. They believe that you see the object simply because it is bright or because light falls on it. Some of the pupils explain the act of seeing by the look or vision going from eye to object.

Stead and Osborne (1979) interviewed 36 pupils between the ages of 9 and 16 as to what ideas they had on light sources and reflectors, on the propagation of light and on the act of seeing. They also gave a written multiple-choice test with corresponding questions to 379 pupils. Both studies show that few pupils understand light as something that propagates far from the source of light. The majority of pupils were of the opinion that light propagates a little further from the source of light at night than during the day. As far as this question is concerned, no difference was noticed between those pupils who had had lessons on optics and those who had not.

THE QUESTIONS INVESTIGATED

In the nine-year Swedish Comprehensive School, the pupils are taught optics chiefly in Form 8. They are then about 14 years old. The optics treated is essentially geometrical optics. With the history of ideas in mind, it is natural to put the following two questions and to allow these to refer to pupils both before and after the optics course:

1. To what extent do the pupils use the model "light exists and propagates in space" to explain optical phenomena?
2. What ideas do the pupils have about the link between object and eye when common objects are seen?

As far as pupils who have not been taught optics are concerned, the answer to Question 1 is of interest because the text books practically take it for granted that the pupils understand the model in question. In the course the emphasis is laid on reflection, refraction and systems of lenses. To keep up, the pupils must understand from the very beginning that light exists and propagates in space. If a large number of pupils lack this understanding, the course must be changed.

The answer to Question 2 can supply information as to whether pupils have alternative ideas about the link between object and eye, for instance the idea of visual rays, before they begin the course. If this is the case, the teacher may need to take them into consideration.

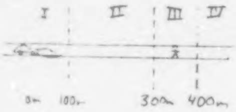
As far as the pupils who have been taught optics are concerned, the answers to both these questions provide an indication of both the effectiveness of the teaching and the future level of knowledge in this country with regard to the basics of optics.

In addition to the questions discussed above, we wish to obtain answers to the following:

3. How do pupils explain a phenomenon of refraction?
4. How do the pupils explain that white light changes colour when passing through a filter?

Both refraction and colour are dealt with thoroughly in Form 8. It is therefore of interest to know how pupils who have attended lessons answer these questions. However, phenomena of refraction and colour are found in everyday life too. It is thus conceivable that pupils have alternative ideas about these before they receive instruction, ideas which may need to be taken into account by the teacher.

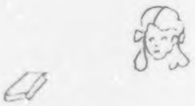
TEST PROBLEMS



PROBLEM 1 (Compare Question 1 and 2.)

On a clear, dark night a car stand parked on a straight flat road. The car has its headlights dipped. A pedestrian, who is standing in the road, can see the headlights. The figure is divided into four sections. In which sections is there light?
Explain your answer.

PROBLEM 2 (Compare Questions 1 and 2.)



Lisa and her physics teacher are discussing seeing.

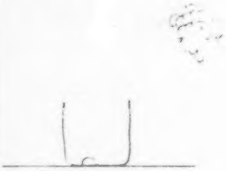
Teacher: Explain how you can see the book!

Lisa: Signals go along nerves between the eyes and the brain.

Teacher: Yes, this happens between the eyes and the brain. But there's some distance between the book and the eyes. Does anything happen between them?

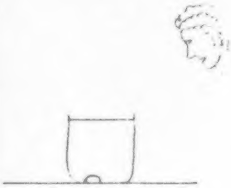
What would you answer? Draw and explain.

PROBLEM 3 (Compare Questions 1,2 and 3.)



Johan looks down into a bucket. There is a piece of plasticine on the bottom. Johan cannot see the plasticine.

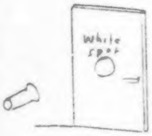
Explain why Johan cannot see the plasticine. Add a drawing to your explanation, if you like.



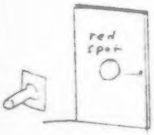
Now the bucket is filled with water. Johan can then see the piece of plasticine, in spite of not shifting his position. The bucket is also in the same place as before.

Explain why Johan can see the plasticine when the bucket has been filled with water. Add a drawing to your explanation, if you like.

PROBLEM 4 (Compare Questions 1 and 6)



A torch is shone on a door. A spot of white light can be seen on the door.



A plate of transparent red glass is placed in front of the torch. A spot of red light is then seen on the door.

Explain how the plate of glass changes the colour of the spot of light from white to red. Add a drawing to your explanation, if you like.

CHOICE OF PUPILS

We have allowed various classes in schools in Göteborg to solve the problems 1 - 4. The classes have not been chosen randomly. We have, however, made enquiries regarding the general level of the participating schools with reference to the results of standardized achievement tests in Swedish and mathematics. On the basis of these, we think that the participating classes are not strongly unrepresentative of Sweden.

RESULTS

PROBLEM 1

We have found the following categories of answer.

A. Not answered or answered without explanation

B. There is light in section I, possibly in II also

B_1 Only the car system is taken into account

The headlight reach this far (I) *)

You can see it in the picture. (I)

The batteries aren't strong enough. (I)

B_2 Both the car system and the pedestrian are taken into account but, although the pedestrian can see the headlights, the pupil thinks that there is light only in I, possibly II.

The headlight doesn't reach very far, but you can see the points of light a long way off. (I)

The pedestrian can see a couple of hundred metres up to the light. (I and II)

I don't think dipped lights can be seen more than 100 m away. The reason why the person can see the light is because he can see the light in section I, but there isn't any light in section III. (I)

C. There is light in sections I, II and III, and possibly IV too.

C_1 Various explanations (rather a small category)

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*) The sections in which there is light, according to the pupil, are given in brackets.

C_2 The pedestrian can see the light, therefore light in I, II and III, possibly IV.

If it wasn't in three sections, he wouldn't see the light. (I, II and III.)

If you can see the light, there must be light. (All)

C_3 The light reaches (almost) to infinity

The pupils in this category think that there is light in all the sections.

The light goes on to infinity, only the ground bends after a while so that the light goes above eye-level.

The light waves propagate themselves almost to any distance, even if they thin out the further away they come. If the pedestrian can see the car's headlights, the light has reached him in sufficient strength to be seen with the naked eye. Then it continues even further on.

D. Others

Section IV. The car pushes the light as far as section IV. (Only section IV is indicated.)

Table 1 below shows the distribution of the different categories of answer described.

Table 1. Problem 1: In what sections is there light? Distribution of pupils' answers and explanations by categories. (%)

	A	B (I or II)		C (I+II+III poss.IV)			D
		B_1	B_2	C_1	C_2	C_3	
Form 6 (n=103)	22	19	20	7	24	1	6
Form 7 (n=205)	12	25	20	7	30	1	4
Form 8 (n=102)	10	28	25	12	20	3	3
Form 9 (n=148)	11	25	28	7	24	1	3

PROBLEM 2

We have found the following categories.

A. Not answered or not explained.

B. Nothing happens between the book and the eye.

C. The visual system is active

The book is caught up by the eyes.

The girl adjusts her lens to the book. The eyes concentrate on the book.

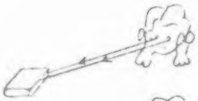
The eyes make contact with the book.

D. It is light. (Light is necessary for seeing)

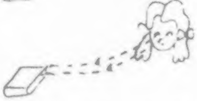
Light shines so we are able to see.

If it had been dark in the room, she wouldn't have seen it.

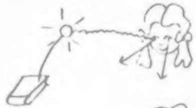
E. Some kind of ray (impulse, look, sight) goes from eye to book.



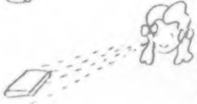
Rays go from the eyes to the book so that we can see the book.



Some kind of eye waves go between the book and the eyes.

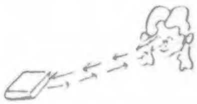


Nothing happens, does it? The eyes see the book. It's got something to do with sight and the brain. The sun shines on the girl. Then rays go from the girl's eyes to the book.

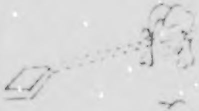


Light is refracted in the lenses and flows out to the book.

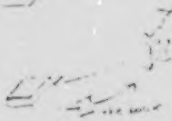
F. Something goes backwards and forwards between eye and book.



The eyes send out some kind of ray, which returns to the head and gives a message.



The brain sends out signals to the eyes, and they go on out to the book and then back again. The picture really comes in backwards into the eye, but it doesn't look like that to the eyes.

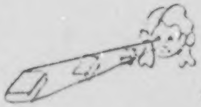


The signal throws back an upside-down book. Then the brain turns the picture the right way up. Then you see the picture and can establish that it is a book.

G. Something enters (goes towards) the eye.

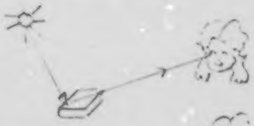
G_1 Image. (Also impression, colour and suchlike)

The image of the book enters through a hole (the pupil) in the eye and sticks on to a wall.

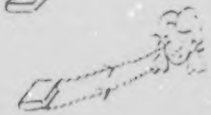


The book is reproduced as a picture on the retina.

G_2 Light or (light-)rays (Also waves and photons)



The book gives off light, which is perceived by the eye.



The book radiates waves in all directions, when they reach the eyes then things happen in the way Lisa described to the physics teacher.

H. Others

The distribution of the categories stated can be seen in Table 2 below.

Table 2 Problem 2. The pupils' explanations of the link between object and eye. Distribution by categories. (%)

	A	B	C	D	E	F	G		H
							G_1	G_2	
Form 6 (n=124)	20	10	24	20	9	3	6	1	7
Form 7 (n=205)	27	3	25	2	7	10	9	11	5
Form 8 (n=136)	23	5	15	9	3	14	5	21	4
Form 9 (n=166)	29	1	13	4	4	5	5	30	9

PROBLEM 3

We have analysed the answers to the second part of the problem. The answers are classified into two main groups, namely concrete explanations and explanations with abstract elements. The abstract elements consist of light ray, visual ray, look and such non-observable things. This is done in writing, sometimes accompanied by a simple sketch.

We have found the following categories:

A. Not answered or not explained.

B. Concrete explanations.

The water makes it lighter, clearer and there's a better contrast in the bucket.

The plasticine is magnified.

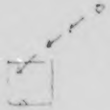
The plasticine appears to have moved.

The plasticine is reflected like in a mirror, e.g. in the side of the bucket or at the surface of the water.

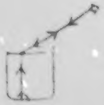
C. Abstract explanations.

C_1 Reflection, mirroring

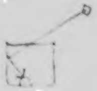
Direction from eye to object



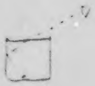
This side that Johan's look lands on probably acts as a mirror as there is water in the bucket. P.S. Have done the experiment but have forgotten it.



The plasticine is reflected in the water.

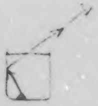


When the water has come into the bucket, the object is magnified and is then easier to see. Or the object is reflected to the edge of the bucket so you can see the plasticine with your look. Or the look bounces to the object.



Unspecified direction

Because the plasticine is reflected by the water in the bucket.

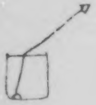


Direction from object to eye

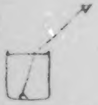
It is reflected in the water.

C$_2$ Refraction

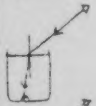
Direction from eye to object ↙



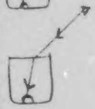
When you look down into the water, your sight is bent at an angle so you can see it.



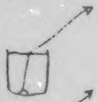
When you look into the water the sight ray is bent downward. That's why you can see it now and not before.



Vision is bent at the surface of the water towards the perpendicular.

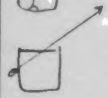


The velocity of light isn't so great in water as in air, so the sight direction is bent. The plasticine seems to be higher up in the bucket.

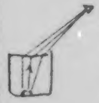


Unspecified direction ↭

The water bends the light.

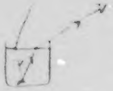


Light is bent in the water, it then looks as if you have moved the object in the bucket.

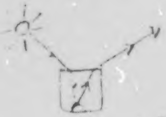


Direction from object to eye ↗

Because when the light rays meet the surface of the water they are bent and that's why Johan can see the plasticine.



The light rays are bent between the air and the water so they get a direction that can reach Johan's eye.



The light is refracted in the water.

D. Others

Table 3. Problem 3. The pupils' explanations of a phenomenon of refraction. Distribution by categories (%)

	A	B	C$_1$			C$_2$			D
			↙	↭	↗	↙	↭	↗	
Form 6 (n=124)	24	51	2	3	1	5	9	0	6
Form 7 (n=205)	8	58	3	2	0	8	12	0	8
Form 8 (n=136)	6	34	4	1	1	24	21	5	4
Form 9 (n=166)	10	29	2	3	1	19	23	7	7

PROBLEM 4

We have found the following categories:

A. Not answered or not explained.

B. The glass-plate makes the colour change

Red plate gives red light.

Only because the plate is red, and then there must be a red spot on the door.

C. The light is coloured red in the glass-plate

The white light is coloured by the sheet of red glass.

The light goes through the red glass-plate, which colours it red.

Light particles (molecules) absorb the red colour. They are affected.

D. The light is refracted in the glass plate

The rays are bent through the red glass plate and become red because of this.

When the light reaches the plate of red glass, the rays are bent and they change colour.

E. Selective transmission of red light

It's only the red rays that penetrate the red glass plate.

The plate fo glass lets only red light through. The rest is absorbed.

The plate of red glass only lets through light of "red" wavelength. If a plate of green glass, for instance, had been put in front after that, no light would come through at all.

F. Others

Table 4. Problem 4. Pupils' explanations of how a filter affects the light from a torch. Distribution by categories (%)

	A	B	C	D	E	F
Form 6 (n=103)	16	61	5	2	0	16
Form 7 (n=205)	7	60	10	8	3	12
Form 8 (n=121)	8	50	12	8	9	12
Form 9 (n=153)	12	43	10	13	10	11

DISCUSSION

The pupils' understanding of the key idea of optics.

A first question in this study is the extent to which pupils make use of the conception that light is something physical that exists and propagates in space, apart from sources and effects. It is no exaggeration to call this the key idea of optics.

For Problem 1 there is only an answer in Category C that indicates that a pupil is using the key idea. Such an answer states that there is light in sections I, II, III and possibly in IV too, and explains why. For Problem 2 there is only an answer in Category C_2 that indicates that a pupil is using the key idea. An answer in this category states that light goes from the book to Lisa's eyes.

Table 5 below shows the percentage of pupils in each form that uses what we call the key idea of optics for problems 1 and 2.

Table 5. Percentage of pupils in each form which uses the key idea of optics for problems 1 and 2.

	Problem 1	Problem 2	Both problems 1 and 2	At least one of problems 1 and 2
Form 6	32	1	0	32
Form 7	38	11	4	44
Form 8	35	21	11	48
Form 9	32	30	11	44

Problems 3 and 4 are not equally unambigous. However, it is possible, by using mild criteria, to make an estimate of the upper limit for the percentage of pupils who use the key idea of optics. Accordingly, for Problem 3 the criterion is Category C, with the sub-categories "un-specified direction" and "direction from object to eye", and for Problem 4 the criterion includes Categories C, D and E. The percentages of pupils who apply the key idea of optics for Problem 3 are 10%, 12%, 27% and 31% in Forms 6-9, inclusive, and 7%, 21%, 29%, and 33% for Problem 4.

Consequently, we find that for each problem not more than 30% of the pupils in Form 9 apply the key idea of optics after attending the course. Table 5 shows that its application varies with the problem concerned. Only about 10% of the pupils in Form 9 use the key idea for both Problems 1 and 2. Before the course the corresponding percentage is lower.

From the point of view of learning these percentages indicate that the Upper School (Forms 7-9) teaching of geometrical optics has little effect. The figures also indicate that the majority of the pupils never grasp the basic theme of the course. The teacher's efforts may be compared to an attempt to build a house without laying a proper foundation.

This means that quite another degree of attention than that now prevalent must be paid to providing the pupils with the opportunity of gaining an insight into what we call the key idea of optics. But the teaching material for the Upper School largely takes it for granted that the pupils can immediately understand that light is something that exists and propagates in space. It is probable, too, that the teacher does not systematically train the pupils with respect to this basic understanding, it being so much a part of the teacher's concept of the world that he or she neither thinks of how fundamental it is nor that it can be a problem for the pupil.

As no attention at all is being paid to the problem of getting pupils to understand the key idea of optics, it is natural to ask, first of all, if it is possible to invent new ways of teaching optics that will ensure that a larger proportion of the pupils will have gained an understanding of the key idea of optics after attending comprehensive school. This is a question of immediate and urgent concern in other countries beside Sweden.

Alternative explanations - concrete answers

As most pupils do not make use of the accepted, basic physical model of light, it is of great interest to take a closer look at alternative explanations. We then find, among other things, that a large group of answers is concrete in character. Those pupils whose answer to Problem 1 is that there is only light in section I think in a concrete way. It is obvious from the drawing that the light (from the car) is only found in section I. The pupils may also know that dipped light lights up the road for about 50 metres. With regard to Problem 2, for instance, the observation that it is light is a concrete one. For Problem 3 the pupils refer to a large number of concrete observations to explain why the piece of plasticine can be seen when water is poured into the bucket. For example, they say that everything looks bigger in water, that it looks as if the plasticine is lying higher up when water is poured in and that the water reflects the piece of plasticine. In Problem 4 the pupils argue: "red glass - red spot", which is a kind of concrete one-one correspondence.

The many examples of different types of concrete explanations found in our study probably cannot be regarded as crystallized stable ideas. Informal conversations about Problem 3 have, for instance, shown that the pupils transfer from one concrete explanation to another when the problem is first presented in written form and then again with real objects. It happens, too, that pupils give several different concrete explanations in a given context.

We think that phychological significance should be primarily attached to the concrete nature of the explanations. Here it is convenient to remind ourselves of the many studies that have, in recent years, shown that the majority of pupils of Upper School age are at what is known as the concrete operational stage (see, for instance, Shayer and Ady, 1981). The pupils' concrete way of thinking is something that the teacher has to accept. This does not mean, however, that teaching should be only concrete. On the contrary, as it is desirable to teach the pupils to think in an abstract way, it is essential that this is deliberately practised in science lessons. How this is to be achieved and to what extent it is possible are questions that remain to be answered.

Alternative explanations - visual rays, looks, etc.

It is striking that the pupils, in their explanations introduce ideas such as vision, look, light from the eyes, visual rays etc. It is of interest to know how widespread this type of conception is - we briefly name it "the visual ray idea". We have therefore worked out Table 6 below. For Problem 1 it is Category B_2 that is relevant, for Problem 2, Categories E and F, and for Problem 3, Categories C_1 and C_2, with a ray from eye to object.

Table 6. Percentage of pupils in a given form that uses the visual ray idea for Problems 1, 2 and 3, for at least one out of three of the problems, and for all three.

	1	2	3	one of three	all (1+2+3)
Form 6	20	12	7	35	2
Form 7	20	17	11	40	1
Form 8	25	17	28	55	2
Form 9	28	9	21	45	2

Table 6 shows that the idea of visual ray is common, but not particularly stable in a given pupil. It is sometimes applied, sometimes not. Is the conception of visual rays a passing, temporary idea then, which pops up in the pupils' heads when they ponder over the problems in this study and which, for that reason, need not be especially taken into account in teaching? The results of Problem 3 indicate that this is not the case. Out of 329 pupils in Forms 6 and 7, 58 (18%) explain how the bit of plasticine is seen by means of the concept of refraction. This is probably the effect of teaching in the Middle School, in which optics is sporadically included. In Forms 8 and 9, 149 pupils out of 302 (49%) use refraction in their explanations, apparently as a result of the Upper School lessons on optics, given primarily in Form 8. This may seem to be a good teaching result. But if we divide the refraction pupils into the sub-categories "visual ray, etc.", "unspecified light direction" and "light from object to eye", we obtain a different picture. Compare Table 7!

Table 7. Percentage of pupils who explain Problem 3 by refraction in different categories.

	Visual ray etc.	Unspecified light direction	Light from object to eye
Forms 6-7 (n=58)	39	61	0
Forms 8-9 (n=149)	43	45	12

Among a considerable number of pupils the correct physical explanations that have been taught have been re-shaped into visual-ray optics. Only a few clearly state that light travels from object to eye. This is a certain indication that the conception of visual rays is a reality that affects the formation of concepts among pupils. We are dealing with quite a stable pre-physical conception, or tendency towards one, which cannot be replaced then and there by the idea of light rays. These two conceptions struggle for supremacy. It is evident that the visual ray idea is well established from such answers as: "The sun shines on the girl. Then rays go from the girl's eyes to the book." (Compare Category E, Problem 2.) Another example of this is provided by the pupil who says: "Vision is bent at the surface of the water towards the perpendicular" (Category C_2, Problem 3).

Alternative explanations - parallels to the ideas from earlier times.

The results of our study show parallels to the ideas formed in earlier times, both in general and in detail.

Generally, we can conclude that the difficulties which the pupils have in understanding the key idea of optics - i.e. that light is something that exists and propagates in space, apart from sources and effects - have also been the difficulties of mankind. The first four propositions in Kepler's work "Ad Vitellionem Paralipomena", 1604, were the culmination of not less than 2000 years of mental exertion. In present-day teaching these 2000 years are compressed into a few minutes, if they are taken into account at all.

At the detailed level we are reminded of the classical problem about the link between the eye and the object seen, which we dealt with in the introduction. When we, 2300 years later, once more formulate the same problem, we find striking parallels between the thinking of Swedish school pupils and that of the philosophers of Ancient Times. The Pythagoreans spoke of an invisible fire that went from eye to object. Euclid introduced the concept of visual ray. Swedish pupils talk of visual rays, looks, impulses, etc, that are emitted by the eyes and which explain seeing and refraction. Empedocles combined a flux from the interior to the exterior with one from the exterior to the interior to explain vision. Category F for Problem 4 consists of related, but not directly parallel, ideas. The Atomists believed that an image, eidola, travelled from object to eye. Category G_1 for Problem 2 provides a clear parallel to this classical idea.

There are naturally differences between the philosophers of Antiquity and Swedish Upper School pupils. For Euclid, for instance, the concept of visual ray was part of a deductive system that was applied consistently to various phenomena. Upper School pupils sometimes use visual rays, sometimes do not, apparently inconsistently.

From Ancient Times we take a 2000-year leap to Kepler and the problem of colour. Like others of his time, Kepler thought that light and colour were two separate things. Colour was a property of the object and light something colourless. When, for instance, light passed through a plate of glass or was reflected by surfaces, it extracted colour. This idea seems to reappear among our Upper School pupils! (Compare Category C, Problem 4.)

In the history of ideas understanding of colour and the phenomenon of colour comes after Kepler formulated his fundamental model of light. With twentieth-century hindsight we can say that this is a logical development, which is nevertheless of educational importance. To understand the phenomenon of colour it is necessary to have a good understanding of the concept of light as an object, that exists and propagates in space.

Concluding remarks

A good understanding of optical phenomena, such as light, shadow and colour, includes at least two essential components. In the first place, there should be a clear idea that light is something physical that propagates in space. It is invisible and colourless. In the second place, it is necessary to understand that when physical light interacts with the retina, which is a part of the brain, the process that leads to the perception of light and colour is initiated. The way in which we use the word light in everyday language does not help us to achieve the above mentioned understanding.

What we call light in our daily speech mainly refers to our experience of light, i.e. an indication of the interaction between physical light and the visual system. "The light is bad in here, it's getting lighter, it's light" are examples of the use of the word light in this sense. In other words, linguistic usage suggests that in everyday life we do not feel any great need to talk about the physical light that, for instance, travels from the printed page to the eye of the reader at this moment. If we do not talk about physical light, it is hardly likely that our children will form any ideas about it, let alone learn to distinguish between light as a physical object and light as perception.

Teachers of physics also talk about light in a vague way. We say, for instance, that white light is split up by a prism into light that is red, yellow, green, etc. Newton, when discussing light rays and colours, put it in another way:

> "The ... rays which appear red, or rather make objects appear so, I call red-making."
>
> "In them there is nothing else than a certain power and disposition to stir up the sensation of this or that colour."

Unfortunately, those of us who teach physics have adopted a mode of language that is unsuitable for use with pupils who cannot yet distinguish between light as physical object and light as perception. We ought to return to a use of language similar to that of Newton's.

We have now attempted to explain why pupils lack an understanding of light before the optics course begins. Linguistic observations can also explain how the idea about light passing from eye to object occurs. We say, for instance, that we throw glances/cast looks. Looks warm us, almost make us melt. We can shoot looks, too. Superman even has x-ray and infra-red sight, which can penetrate walls. This language usage, coupled with the absence of a model of physical light, can create a tendency to explain, for instance, the link between object and eye by visual rays, looks and suchlike.

In this way, we wish to explain why the pupils' ideas on optics show these characteristics before optics lessons begin. We have also shown that everyday concepts are not altered to any particular extent as a result of teaching. We hope that our study will stimulate science teachers to invent new and better ways of teaching elementary optics.

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Student Preconceptions in Introductory High School Physics as Related to Course Achievement

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Introduction

A significant factor in the teaching of many school subjects, including physics, is that students come to many learning situations with some previously formed ideas about the topic. These preconceptions or "alternative hypotheses", Driver and Easley, 1978, can either interfere with learning the formal subject matter or, in the hands of teachers conscious of the existence and characteristics of the most prevalent beliefs, be used to good effect.

That there should be a disparity between the child's interpretation of the physical world and that accepted by physicists is not surprising when we remember that the present state of our understanding of physics has been built up over centuries and has itself undergone radical change over time (Kuhn, 1962). The student has, prior to entering the physics class, also experienced and analyzed his limited environments, building up his own "logical" framework of knowledge which appears to him to be in harmony with his surroundings (Driver, [illegible]). This logical framework is not acquired passively, but is adopted with a strong commitment, directing the student's attention to selected stimuli and determining his interpretation of any problem that is encountered.

Since these alternative hypotheses are built on a small area of awareness the student has available much the same type of data as did people in earlier times. Thus the child may well entertain theories of motion which are Aristotelian in nature. One such idea, that motion requires a force to sustain it, appears quite logical in a world where frictionless motion is never encountered in everyday life. Newton's laws of motion, although more scientifically satisfactory in the analysis of motion, are not likely to be developed by an individual without instruction. This could well be a factor in the perceived difficulty of physics as an area of study - while it explains the physical world, it does so in terms which often differ from the student's direct sensory evidence. Conflicts in adjusting to a new view of the world in order to comprehend concepts in physics may lead the student to lose confidence in his or her own reasoning patterns perhaps bringing about an inability to adapt. On the basis of relevant studies in the literature (Driver, Aguirre),

it appears that the conflicts between the student's spontaneous explanatory framework and accepted physical theories (or the teacher's conceptual framework, which may also differ in detail from current scientific views) has several facets:

1) the interpretation of a teacher's words
2) the predictions the student will make
3) what factors in a given situation the student sees as important

Purpose

The purpose of this study is to explore the nature and extent of preconceptions or "alternative hypotheses" in the area of Newton's First and Second Laws of Motion held by students in grade ten physics classes before beginning formal instruction in the subject.

In more detail, the study attempts to investigate the questions:

1) What is the nature of tenth grade physics students' preconceptions of motion in the conceptual areas of:
   a) inertia
   b) the effect of forces on the motion of an object?
2) How prevalent are the preconceptions?
3) Are there any consistencies in the types of preconceptions held by the student about various situations presented to him or to her?
4) Is there any relationship between the type of preconceptions held and achievement in physics as demonstrated by:
   a) performance on a criterion test
   b) end of term mark in physics

In addition, informal evidence pertaining to the resemblance of preconceptions to earlier views of physics, notably those of Aristotle, sex differences and the influence of scientific and technological activities such as space exploration will be sought.

The Tasks

Task 1. Horizontal Motion Along a Groove

The apparatus consisted of a metal groove supported horizontally by two pieces of wood. Attached to a spring at one end, was a "striker" which could be pulled back by a nail and released. The striker was retracted each time to a marked position to ensure that a constant amount of potential energy was given by the spring. The near side of the marble or ball was placed on another mark so that the spring was always travelling with the same speed when it hit the ball. Although the striker would lose less energy to the smaller ball, the difference in mass of the balls was so small in comparison with the difference between their masses and that of the striker that almost the same energy was given to each ball. More importantly, the students assumed that the energy was the same in each case.

The student was asked to explain what would happen when the first ball was struck and "Why?". This was often difficult for the student to answer because he could not be sure of what was required. If so, he was immediately asked the next question. The ball, a steel marble, was propelled along the groove. It was so arranged that this ball stopped about half way along the groove.

The student was then encouraged to pass the other two marbles so that he could feel their weights relative to that of the other ball without his attention being drawn to this factor. One was a glass marble of the same size but smaller mass than the first, the second was a steel ball with a diameter about twice that of the other two and was therefore considerably heavier.

The student was asked whether there would be any difference in the way these two balls behaved and to explain his answer. Each ball was then shot along the groove and the students were asked to explain the result.

Task 2. Inertia of a Ball in a Cart

A small open cart with sides and a handle was presented to the student. A small marble was placed in the centre of the cart. The student was told that the cart would be sharply pulled along the table and equally suddenly stopped. He was asked to predict what would happen and to give his reasons why.

This task is often used in Junior High School to demonstrate the concept of inertia. Some of the students remembered having seen it performed and some could remember an explanation, although not always accurately.

Task 3. Inertia in Space

While the other three tasks were presented in random order, this task was attempted last so that the student would always have had experience with the inertia in Task 3. It took the student away from the context of the earth into space and tested his ability to transfer his ideas to space.

A large globe of the earth was shown, a model spaceship and plasticine spaceman. The spaceship with the spaceman inside was demonstrated orbiting the earth in a trajectory which took them over the north and south poles. The student was then told: "The spaceman heard a noise outside, put on his spacesuit and went outside to investigate. When the spaceship was here (over the equator) he happened to let go of the spaceship. Where would he be when the spaceship was over the North Pole and why?" It was mentioned that the spaceman was wearing a spacesuit thus indirectly reminding the students, it was hoped, that there is no air and therefore no resistance to movement at the height at which a spaceship is in orbit. When the student has replied, there was often some discussion. Then he was asked what would happen if the spaceman did the same thing in space but this time pushed away from the spaceship. Was there any way he could get back?

Task 4. Acceleration Produced by a Constant Force

In this task, a small cart on a table was attached to a hanging weight by a string over a pully. The length of string was so arranged that the weight reached the ground as the cart touched the pulley. There would thus be a constant acceleration when the cart was released from its initial position.

The student was first asked to predict what would happen when the cart had been pulled back and released. The experiment was performed and the student asked the reason for the type of movement. Next, the string was made longer and the student asked whether there would be any difference in the movement and why. The weight would reach the ground when the cart was about half way to the pulley and the cart would travel then with a speed slightly decelerated by friction.

The Criterion Test

In order to make a reliable comparison of the achievement of the students a criterion test was devised. This test was composed of twelve items,

Table 1

Distribution of subjects by age

Sex	Age in years on September 30, 1979				
	14.6-15.6	15.7-16.6	16.7-17.6	17.7-18.6	18.7-19.6
Girls	6	8	-	-	-
Boys	13	10	1	1	1
Total	19	18	1	1	1

The transcripts were analysed in three ways:

First, it was found that several statements made by different students expressed the same concept. The statements for each task were listed and grouped under the concept expressed. A chart indicating the order in which they were expressed provided a conceptual profile for each student. These data were aggregated into a frequency table for the concepts for each task.

Second, the concepts expressed for each task were reviewed and compared to yield a progression from the most primitive to the most sophisticated explanation or description. From this, and the student's conceptual profile, a cognitive stage, determined by the degree to which he or she conserved motion, was ascribed to each student for each task.

Thirdly, the concepts expressed and cognitive stage described were related to performance on the criterion test, with individual items on the test, and with end of term marks.

three items dealing with each of the topics involved in the tasks. For the three items pertaining to each task, one was recall, one involved application of formulae or knowledge taught in grade ten physics and the other involved transfer of learned material to a new area.

The criterion test was set in three schools at the end of the semester as an important review which the students believed carried marks. At the fourth school from which five students participated, the test was given as the end of section test. The tests were marked by the investigators. One student missed the test and for one other the test paper was mislaid.

End of Term Marks

The teachers' end of term marks were collected for thirty eight students - two students had dropped the course. These marks were used to investigate what relationship might exist if any, between a student's achievement in introductory physics and his conceptions at the beginning of the course.

The Subjects

The subjects for this study were 40 grade ten physics students from four randomly selected high schools in the Edmonton Public School system. Five students were randomly selected from each of eight randomly selected physics classes. Twenty-six of the subjects were male and fourteen female. Table 1 presents the distribution of subjects by age. The interviews, were tape-recorded with the students' consent.

Results

Table 2 presents a summary of the replies of 92.5 per cent of the students. Of the remaining 7.5 per cent of students, one said he "didn't know" and the other two gave no explanation as such. The most common response, given by half of the students, suggested that the distance travelled depended only on the energy given to the ball. The act of moving uses up the energy or force given to it until it stops, thus giving a constant relationship between energy or force* and the distance travelled.

Thirty per cent of the students expressed the concept of conservation of motion, but only half of these mentioned it as a first response. It was found on this task that while a large number of responses can be obtained from the students, only a few concepts are represented. Gravity, as well as being confused with energy, weight, and momentum, has a personal and often undefined meaning. Although the task seems to be very simple, it is possible for a student to give a false prediction for the movement and to persist in this idea in spite of visual evidence to the contrary.

When two other balls were introduced to the task, the students attention became centered on the contribution of weight or mass to the distance travelled. This affected the distribution of replies but not the type of concept used. The concepts as classified were:

1. There is a fixed relationship between the force or energy given to the ball, the mass given to the ball, and the distance travelled.
2. The distance depends on the inertia of the ball.
3. Gravity or weight is a retarding agent.
4. The distance travelled depends upon the resistance to the ball.

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*The terms energy and force often appear to be perceived by the students as interchangeable and do not have the precise meanings used in science. Energy (or force), as used in this context, is some undefined and undifferentiated quantity given by the spring to the ball which causes it to move and which is used up in the course of the movement.

Table 2

Distribution by sex of occurrence of concepts explaining motion of single ball

Pattern of response	Per cent responding Boys N=26	 Girls N=14	 Total N=40
Continuous force is required			
Only response	0	7.1	2.5
Later modified	7.7	0	5.0
Total	7.7	7.1	7.5
Constant relationship between force and distance travelled			
Only response	27.9	57.1	37.5
Plus a retarding force	3.8	7.1	5.0
Plus conservation of motion	7.7	7.1	7.5
Total	38.5	71.4	50.0*
Retarding force of gravity acts			
Only response	3.8	0	2.5
Plus friction	7.7	14.3	10.0
Plus conservation of motion	7.7	0	5.0
Total	19.2	14.3	17.5
Retarding forces of friction and/or air resistance act			
Without conservation of motion[a]	19.2	14.3	17.5
Plus conservation of motion	30.8	14.3	25.0
Total	50.0	28.6	42.5
Conservation of motion			
Total	36.5	14.3	30.0

[a] Only one student mentioned retarding forces only

*x^2=5.0, 0.2>p>.05 for distribution by sex

Table 3

Distribution by sex of occurrence of concepts explaining motion of balls of different size and weight

Pattern of response	Per cent responding Boys N=26	 Girls N=14	 Total N=40
Fixed relationship between force/energy, distance and mass			
Without friction	19.2	57.1	32.5
Followed by friction	15.4	21.4	17.5
Total	34.6	78.6	50.0*
Relationship between inertia and distance			
Without friction	34.6	42.9	37.5
With friction	19.2	17.1	15.0
Total	53.8	50.0	52.5
Gravity/weight as a retarding agent			
Without friction	15.4	21.4	17.5
With friction	7.7	0	5.0
Total	23.1	21.4	22.5
Resistance slows down			
Without conservation of motion	38.5	14.3	30.0
With conservation of motion	7.7	7.1	7.5
Total	46.2	21.4	37.5
Conservation of motion			
Explicitly stated	7.7	7.1	7.5
Speed is the determining factor			
With conservation of motion	3.8	0	2.5

*x^2= 7.0 .01>p>.001 for distribution by sex

5. Conservation of motion is explicitly stated.

6. Speed is a determining factor.

Table 3 presents the distribution of these concept. Also given is the frequency with which each concept was accompanied by some indication of the importance of friction or of conservation of motion.

The chi square was used to compare the frequencies of similar conceptions used by individual students on the two tasks. The idea of friction in the two tasks, and the invocation of the concept of gravity both attained statistical significance ($p < 0.05$). Girls are twice as likely as boys to suggest that the distance a ball travels depends only on its size and the force given ($p < 0.05$).

In summary, the students mental images were found to range from elementary Aristotelian ideas where continued horizontal motion requires a constant force to more sophisticated Newtonian conceptions of conservation of motion. These ideas were not mutually exclusive, often both being expressed. If one accepts primacy of response as an indicator of the relative importance of intuitive ideas, conservation of motion appears relatively infrequently. Terms such as energy, force, and pull of gravity are usually used in a colloquial sense. The first two are often used interchangeably while each may be used as a quantity related to mass. When gravity was used in this way, its possession tended to slow down the movement of a body. Of the fourteen students who mentioned the pull of gravity as an agent of retardation three said the greater weight or pull increased friction and nine implied that the force of gravity downward would slow down the horizontal motion.

Task 2

In analysing the replies to this task, four groups of concepts, indicating increasing levels of understanding emerged.

1. At the most elementary level, the agency of some force was proposed as pushing the ball backwards or forward or holding it stationary when the cart stopped.

2. Somewhat more mature, the motion was one where an agent of weight or gravity was suggested which seemed to resemble inertia.

3. A more sophisticated response recognized more fully the idea of inertia, acknowledging that the ball does not "wish" to change its state of rest or of motion.

4. Inertia, in the scientific sense.Table 4 presents the frequency with which these responses occurred. The total is considerably more than 100 per cent because many students gave replies which fell into more than one category or gave a different type of response for the second part than for the first.

The most frequent response was that given by forty per cent of the students who explained the relative movement of the ball and cart by a force or a cessation of force.

It seemed marginally easier for students to explain the inertia of the moving ball when the cart stopped than when it was first pulled. Twenty one students seemed to understand the inertia of the moving ball compared with seventeen who appeared to understand inertia of the stationary ball. The concept of weight or gravity as a factor similar to inertia was invoked by five students, compared with seven in Task 1 when describing the motion of one ball and ten in comparing the motion of three balls. Three students thought the air pushed the ball to the back of the cart when the cart was first pulled -- a primitive explanation.

It is not difficult to understand the reasons for this type of explanation. A force acting on a body can only be perceived by the results of its action. When students do not notice the ball's movement relative to an external framework, they can only explain its movement in the cart as the result of the action of a force of forces. Piaget, (Inhelder and Piaget, 1958) names relativity of motion as one of the eight formal operational schema (pp. 307-329). In discussing the problems associated with this task of the ball in the cart, Piaget (1974) says: "It takes a long time to understand the inertial processes and one can easily see why. Admitting that a marble moves back in relation to a support in motion and stays in place in relation to external references is both to resist the suggestions of transmissions and to coordinate two systems of reference. On the other hand, the conservation of a rectilinear and uniform movement especially when it manifests itself after the support stops... is not a conservation like any other since it deals with the movement as a state and not with static properties. (p.85)

Table 4

Distribution by sex of occurrence of concepts explaining motion of ball in cart

	Per cent responding		
	Boys	Girls	Total
Possession of relative motion	N=26	N=14	N=40
Agent of a force			
Without relative motion	19.2	21.4	20.0
With partial relative motion	7.7	21.4	12.5
With relative motion	7.7	7.1	7.5
Total	34.6	50.0	40.0
Weight or gravity as factor			
Without relative motion	0	7.1	2.5
With partial relative motion	0	7.1	2.5
With relative motion	11.5	0	7.5
Total	11.5	14.3	12.5
Anthropomorphic explanations			
With partial relative motion[a]	3.8	21.4	10.0
With relative motion	23.1	0	15.0
Total	26.9	21.4	25.0
Inertial explanations			
With partial relative motion	7.7	21.4	12.5
With relative motion	50.0	21.4	40.0
Total	57.7	42.8	52.5

[a] All students giving an anthropomorphic and inertial explanation had some idea of relative motion.

Task 3

While the other tasks were presented to students in random order, this task was always presented last to observe any transfer of concepts of inertia from a terrestrial to a space environment. Table 5 shows the frequencies of various predictions of the spaceman when the spaceship is over the North Pole. Almost half of the students placed him over the equator, that is, with no horizontal motion. Of the twenty students (one-half of the sample) expecting the spaceman to lag behind the spaceship, seven mentioned that the effect of gravity on the man and spaceship would be different, the spaceship being pulled around faster because it is heavier. This is surprising after Task 2, where six of these seven students expected the larger ball to go slower and stop sooner. Again, this is an Aristotelian concept - that gravity has less effect on a smaller object. Many students had a confused idea of what orbiting the earth meant. Their preconceptions often show the influence of what they have heard or seen on space travel and from science fiction.

Table 6 gives the distribution of the first replies of the students. Comparing figures with Table 5, the later replies tended to place the spaceman either with the spaceship or closer to it. There is a significantly larger proportion of girls than boys who suggested the spaceman would remain over the equator when firstresponding to the question where the spaceman would be. However, if considering the response as being the most primitive, the two boys who suggested the spaceman would go in the reverse direction should be included. This gives chi-square for distribution by sex of the most primitive answer as 3.24 which is not significant at the .05 level.

Table 5

Distribution by sex of total occurrence of predictions of destination of spaceman in orbit

	Per cent responding		
	Boys	Girls	Total
Position and speed of spaceman	N=26	N=14	N=40
At same speed as spaceship			
With spaceship	50.0	21.4	40.0
Above spaceship	3.8	0	2.5
Total giving spaceman same speed	50.0[a]	21.4	40.0[a]
Slower than spaceship			
Dragging behind	38.5	57.1	45.0
Moving outwards	11.5	0	7.5
Spiralling towards earth	15.4	7.1	12.5
Total expecting retardation	50.0[a]	57.1[a]	52.5[a]
Staying over equator			
Floating or stationary	26.9	50.0	35.0
Floating away	0	7.1	2.5
Toward earth	19.2	7.1	15.0
Total expecting no linear motion	38.5[a]	64.3	47.5[a]
In reverse direction			
Down to desk	11.5	0	7.5

[a] Some students altered their replies by changing the effect of gravity so this is not the total of replies but is the total number of students giving this reply.

Table 6

Distribution by sex of occurrence of preditions of destination of spaceman in orbit. First reply

	Per cent responding		
	Boys	Girls	Total
Position and speed of spaceman	N=26	N=14	N=40
At same speed as spaceship			
With spaceship	34.6	7.1	25.0
Further out than spaceship	3.8	0	2.5
Total	38.5	7.1	27.5
Slower than spaceship			
Dragging behind	19.2	28.6[a]	22.5
Moving outwards	3.8	0	2.5
Spirally downwards	3.8	7.1[a]	5.0
Total	26.9	35.7	30.0
Staying over equator			
Floating or stationary	23.1	50.0	32.5
Floating away	0	7.1	2.5
Moving toward earth	3.8	[illegible]	5.0
Total	26.9	64.2	40.0*
In reverse direction			
Down to desk	7.7	0	5.0

[a] One girl thought the spaceman would follow the spaceship for a while then spiral towards earth. She is counted twice

* For this distribution by sex, $\chi^2=5.29$, $.02<p<.05$

In summary, almost half the students expected the spaceman to stay at the equator. Only half of the remainder of the students predicted he would stay with the spaceship. Three students failed to see the globe out of context of the laboratory for a little while thinking of gravity acting "downwards" rather than towards the earth. Nearly half of the students thought that the spaceship was propelled by engines or rockets when in orbit while one other student described it as being "programmed" to circle the earth. Some students thought the world turned underneath the spaceship.

There were many misconceptions about gravity. Among them were:

a. There is no gravity because the spaceman is weightless.

b. There is no gravity because there is no atmosphere.

c. Gravity acts on the spaceship not on the spaceman. In space travel it is the man who is described as being weightless, not the spaceship.

d. Gravity is sometimes used as the "force forwards" similar to inertia. If this force is less because the spaceman is lighter, he goes slower. If gravity is absent, he does not continue forward.

e. The spaceman can remain stationary above the earth in the earth's gravitational field without being pulled to earth because the moon does not move to earth. There are various reasons for this including balancing gravitational forces from the moon or sun or there is no reason at all.

Except for those boys who had studied space science as a hobby, most students' ideas of space were strongly influenced by television and science fiction. At least one student expressed scepticism: "Well that's the way the spaceman floats on television".

Task 4

The three previous tasks were concerned with students understanding of inertia of stationary and moving objects, that is, with Newton's first law of motion. The fourth task deals with accelerated motion: Newton's second law. Its inclusion was an attempt to ascertain whether there was an attempt to ascertain whether there was any relationships between the distribution of understanding of the two laws.

Table 7 presents the distribution of the student explanations for the perceived increase in speed. The three explanations were nearly equally favored by the thirty-three students who attempted an answer. The results are similar to those obtained by Aguirre (1978) with students six to fourteen years of age and with Piaget (1974). As was the case with Robertson and Richardson (1975), nearly ninety per cent of respondents predicted constant acceleration. In summary, the concept of acceleration presents little difficulty for students of this age.

Table 8 presents the total percentage of students who were assessed in these stages on Task 1A and Task 1B and also on the task as a whole. Results are also presented by sex. If a student demonstrated conservation of motion on one part, he was assessed as though he demonstrated conservation of motion on the whole task.

It can be seen that boys tended to dominate the upper levels of Stage II and Stage III. If the stages are taken as a whole, the results are similar for both sexes: slightly more than half of the students were placed in Stage II Student Preconceptions Related to Achievement.

Table 9 presents the correlations between the first three tasks, physics achievement, and cognitive stage.

Table 7

Distribution by sex of occurrence of concepts explaining acceleration of cart pulled by constant force

	Per cent responding		
	Boys	Girls	Total
Reason for acceleration	N=25	N=14	N=39[a]
Pull of gravity greater near earth	28.0	21.4	25.6
Falling body increases speed	44.0	7.1	30.8*
Speed or energy increases	28.0	28.6	28.2
Don't know	0	42.9	15.4**

[a] One interview was not recorded on tape for this task.

* $\chi^2 = 4.12$, for distribution by sex, corrected for small expected frequencies. $p < .05$.

** $\chi^2 = 9.58$, for distribution by sex, using Yates correction for small expected frequencies. $0.01 > p > 0.001$.

Table 8

Distribution of cognitive levels in tasks

Cognitive stage	Task 1a	Task 1b	Task 1	Task 2 Inertia	Task 2 Rel.mot	Task 3	Task 4
			Percentage responding				
Girls							
Stage IIA	57.1	78.6	50.0	14.3	(37.5)		33.3
Stage IIB	7.1	7.1	7.1	42.9	(7.1)	50.0	8.3
Stage IIIA	14.3	7.1	28.6	28.6	(28.6)	28.6	33.3
Stage IIIB	14.3	7.1	14.3	14.3	(28.6)	21.4	25.0
Boys							
Stage IIA	30.8	46.1	26.9	7.7	(30.8)		20.8
Stage IIB	3.8	19.2	26.9	26.9	(7.7)	38.5	4.2
Stage IIIA	19.2	26.9	11.5	26.9	(11.5)	26.9	50.0
Stage IIIB	38.5	7.7	34.6	38.5	(50.0)	34.6	25.0
Total							
Stage IIA	40.0	57.5	35.0	10.0	(32.5)		25.0
Stage IIB	5.0	15.0	20.0	32.5	(7.5)	42.5	5.6
Stage IIIA	17.5	20.0	17.5	27.5	(17.5)	27.5	44.4
Stage IIIB	30.0	7.5	27.5	30.0	(42.5)	30.0	25.0

Table 9

Correlations between cognitive stages and achievement in physics

	Task 1	Task 2 Inertia	Task 2 Rel.mot.	Task 3	End of term	Criterion test
Task 1						
Task 2 Inertia	0.37*					
Task 2 Rel.mot.	0.48**	0.70***				
Task 3	0.33	0.34*	0.55***			
End of Term	0.26	0.12	0.26	0.03		
Criterion Test	0.43**	0.10	0.43**	0.49**	0.52***	
Task 4	0.13	0.16	0.12	0.10	0.07	0.12

*0.05 $\geq p >$ 0.01

**0.01 $\geq p >$ 0.001

*** $p \leq$ 0.001

The student's performance on the criterion test was significantly related to one preconception on each task. In Task 1, the initial explanation the student gave for the movement of a single ball was positively correlated to achievement on the criterion test, ($r = 0.43$, $p < 0.01$). That is, the more sophisticated the reply to this first task, the better the student tended to perform on the criterion test. In Task 2, those students who gave as an explanation for the movement of the ball in the cart some reaction or force, were negatively correlated with achievement on the criterion test. The value of this correlation was $r = 0.43$, ($p = 0.01$). In Task 3, the possible positions for the spaceman were numbered, those nearest the spaceship having the highest score. The initial responses of the students were related to performance on the criterion test, ($r = 0.40$). The probability for this occuring by chance is less than 0.02. In Task 4, the explanation that the cart gains momentum or speed from the constant applied force was less strongly related to achievement, ($r = 0.37$, $p <$ 0.05). It seems that those students who have the more mature preconceptions are able to do better on this type of test. It may be that these preconceptions do not reflect some innate characteristic but in many cases are acquired. In these cases interest and experience could cause relationships such as those reported.

Achievement on End of Term Marks

On all the preconceptions tested for relationship with other factors there seemed to be no significant correlations with the end of term marks. There may be some preconceptions which were omitted that would show a significant relation.

Relationship between Achievement Marks

There was a positive correlation between scores on the criterion test and end of term marks ($r = 0.52$, $p = 0.001$) At one school, from which there were five students, the criterion test was used as an end of section test and therefore would contribute to end of term marks. At the other schools the criterion test was stressed beforehand as an important test but was not included in the end of term mark. It should be remembered that the end of term mark reflected performance on other sections of physics than the narrow field of Newton's first two laws reflected in the criterion test. This is possibly one reason why there is no significant relationship between end of term mark and preconceptions.

Cognitive Stage Related to Achievement

Criterion Test

The criterion test was related to the cognitive stages assigned in Task 1 and Task 3. The correlations were respectively, $r = 0.43$, $p = 0.010$, and $r = 0.49$, $p < 0.01$ (see Table 9). An earlier assessment of cognitive stages in Task 2 gave greater weight to the perception of relative motion. These assessed stages were also related to the criterion test, ($r = 0.43$, $p < 0.01$).

End of Term Marks

End of term marks were not significantly related to any assigned cognitive stages. As suggested above this may reflect a broader base of subject matter or that end of term marks do not test cognitive stage.

Variables Influencing Preconceptions

Historical Antecedents

Many of the preconceptions demonstrated in the students' responses resemble beliefs of ancient philosophers especially those of Aristotle. Several students imagined that the air was a factor in sustaining motion by "turbulence" - swirling over the object to push it from the other side. There is no way to ascertain whether they were in any way influenced by diagrams in the Physics text book. If they were, they had not read the captions with care. There was also a tendency to feel that gravity acted with a greater effect on a heavy body than on a light one. This too was a Greek belief in the case of falling bodies. Without checking experimentally the Greek philosophers stated that heavy bodies always fell faster than light ones. Several students described motion as if the body lost energy or momentum as it moved, that is , as if motion was self-expanding. This was an idea introduced by Philoponus in the fifth and early sixth centuries A.D. That the beliefs of ancient philosophers should be reflected in the student of today should not cause surprise for the Greek philosophy explained everyday phenomena with common sense ideas. Science does not do this. Physics teaches about a seemingly unreal world outside of the experience of students.

Space Travel, Science Fiction and Previous Teaching

Modern science does have an influence on the preconceptions of students particularly, of course in relation to problems in space. However, the conceptions acquired from space travel sometimes distort the alternative framework away from the generally accepted structure of knowledge. The term weightlessness applied to the spaceman is misleading. Students sometimes reluctantly assume that gravity acts on the spaceship but not on the spaceman.

At other times they assume that there is no gravitational field and then must invent an agent to hold the spaceship in orbit - an engine in the spaceship or even just that the earth turns underneath.

Science fiction plays its part. If a spaceman leaving a moving spaceship in a film just floats away then conservation of motion is not reinforced in the student's mind. But might it not be that a student who does not conserve motion does not see the spaceman still moving when he leaves the spaceship?

Some students demonstrated a remarkable sophistication with regard to their conceptions. In many cases interest was a major factor though the reverse was not always true. Not all the students who professed interest in science possessed mature conceptions. Some influence due to teaching was evidenced. Many students had learned from teaching on inertia in the case of the ball and cart though sometime inability to perceive relative motion interfered with learning.

Most students had learned that gravity was a force pulling downwards but this did not prevent them accrediting it with slowing down horizontal motion and in maintaining it as in situation of inertia of a moving object.

Gender Influences

There was a significant tendency for girls to do better on end of term marks than for boys, (p 0.05). Further analysis indicates that the correlation between end of term marks and on the criterion test is gender linked. For boys the correlation is highly significant, ($r = 0.73$, $p < 0.001$) whereas for girls there is no significant relationship, ($r = 0.35$, $p < 0.05$).

This suggests that while girls are diligent and work hard on terms marks, they are not as able to tackle the type of question set on the test as are the boys.

There was less agreement also between the performance of girls on the tasks and their achievement on the criterion test than there was for boys. This is probably due to the proponderance of primitive replies in the girl's answers to the tasks which is probably due to their lack of experience in the world of physics.

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REINVENTING ELECTRICITY

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THE PROBLEM

A growing body of research indicates that instruction in electricity and magnetism frequently fails to provide students with the ability to reason effectively about electric circuits. In particular, the key idea of electric potential tends to remain poorly developed and confused with the current concept. My purpose this morning will be to suggest some instructional materials and methods that may be helpful in alleviating this problem.

As I see it, presently favored approaches in electricity instruction are hampered by two major difficulties.

One of these is the enormous perceptual difference between observable circuit phenomena and the macroscopic electrostatics experiments that are employed to generate fundamental concepts. This makes it difficult for students to imagine circuit behavior as deriving from electrostatic events occuring within an invisible system of mobile electric charge. The presence of batteries in electric circuits then makes it tempting to attribute too much of the observed behavior to these very obvious causal agents and too little to the action of electric charge on itself.

A second major difficulty, I suggest, is the presentation of electric potential as an energy-related rather than a force-related concept. When introduced in this manner, the concept becomes too heavily associated with an abstract structure of energy book-keeping and too little related to intuitive notions of pushing-and-shoving within the system of mobile charge. Such an approach invites problems with causal reasoning.

The recent work of Cohen, Eylon and Ganiel,[1] speaks directly to the the latter issue. These authors studied the circuit concepts employed in problem solving by Israeli high school students who had completed a year of electricity and magnetism. The students came from good high schools, with experienced physics teachers, and their level of preparation was equivalent to first-year college in the U.S. or the A level in the U.K.

The study draws the following conclusions: "Current is the primary concept used by students, whereas potential difference is regarded as a *consequence* of current flow, and not its *cause*.... We believe that pd is the prime concept since it *causes* the flow of current. Although considerable time is spent in the teaching of pd in school or in college, we claim that many students do not see its central role and consider current to be the prime concept.... A possible remedy may be the introduction of semiquantitative models or analogies that would explain the role of the source not only as an energy supply but also as 'pushing' the charges with a certain 'pressure'."

A PROPOSED REMEDY

As a way out of these difficulties, I propose first of all to generate fundamental concepts through hands-on experimentation employing large-value capacitors as sources of potential difference and miniature light bulbs as indicators of charge displacement. The use of capacitors permits investigation of electrostatic phenomena directly in circuit contexts. Very large capacitance values can stretch the time scale of events sufficiently for variable potential differences to be experienced concretely through their effect on bulb lighting.

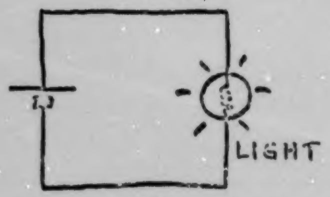
I propose further to exploit the analogy between phenomena associated with the buildup and depletion of electric charge in capacitor plates and phenomena associated with the compression and rarefaction of air in containers. Once students start thinking about the similar behaviors of compressed charge and compressed air, they readily intuit the "pushing" action and the "pressure" concept which Cohen, Eylon and Ganiel suggest are important for effective reasoning about cause-effect relationships in electric circuits.

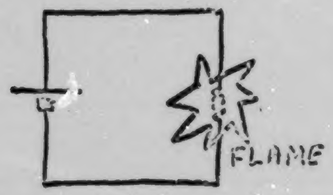
This approach offers opportunities for the design of instruction that builds on students' prior experiences outside the domain of electricity, thus enabling them to develop causal concepts from intuitive reasoning. It also offers opportunities for exploiting the experience of surprise -- the collision of students' overgeneralizations and misconceptions with the evidence of their senses -- to promote conceptual growth.

THREE MODELS OF BULB LIGHTING

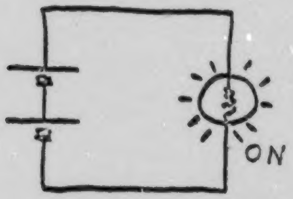
I have found that the following pair of preliminary experiments provides students with a useful common core of information that helps focus their thinking about possible causal models.

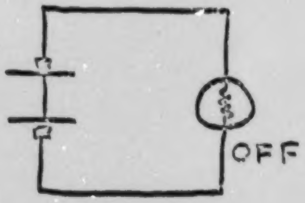
The first experiment involves removing the glass envelope of a light bulb and observing that the filament bursts into flame when it lights up. This makes it clear that filaments light up because they are hot, and creates the need for an explanation of why they are hot.





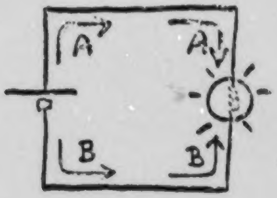
The second experiment involves lighting a bulb with two batteries connected in series, and then observing the bulb's failure to turn back on when the orientation of one battery is reversed. This makes the very important point that the terminals of a battery are functionally different. If they were functionally identical, a reversal of battery orientation could not change the bulb's response.



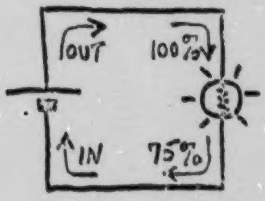


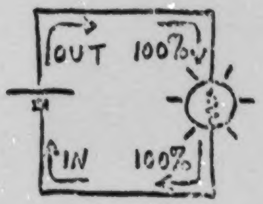
Functionally different battery terminals are consistent with three simple models of hot-filament bulb lighting. I'll call these the "sink" model, the "catcher" model and the "friction" model. I have found it productive to invite beginners to consider all three, and in the following order.

The sink model illustrated here assumes that different substances are emitted at different battery terminals, and that heating is caused by the two substances coming together and interacting in the filament. This model provides an increasingly improbable explanation for the behavior of complex circuits, and tends eventually to fall of its own weight. I feel it is useful to deal with the sink model explicitly, however, because it tends to be the preferred initial option for a substantial minority of students.



Motion in different directions at different battery terminals is consistent with two simple models. The catcher model assumes that heating is caused by partial absorption of a single mobile substance as it passes through the filament. The friction model, on the other hand, holds that none of the mobile substance is absorbed, and that heating is caused by that substance rubbing against the fixed material of the filament while passing through. The catcher model tends to be by far the more popular among beginning students, and is quite capable of surviving a year of college physics.

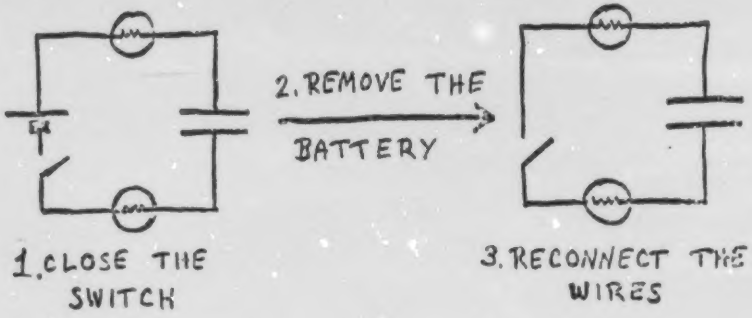




INTRODUCING CAPACITORS

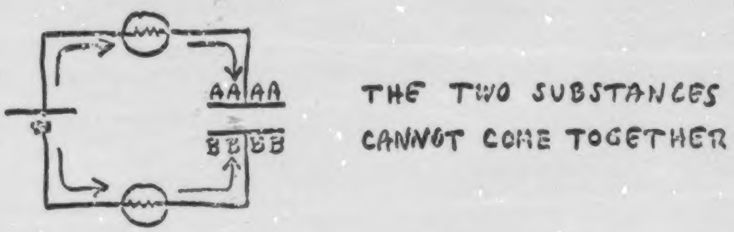
After experiments designed to identify conducting and insulating materials, and a demonstration of the sandwich-like construction of capacitors, the time is ripe for experiencing the effects of charging and discharging capacitors through light bulbs.

Here is a circuit which I have found useful for instructional purposes. The capacitor is nonpolar, usable at up to 20 volts, and has 5,000 microfarads capacitance -- a beautifully miniaturized product. Such capacitors are not available off-the-shelf, but they can be manufactured to your specifications at moderate cost.



Students invariably intuit that the capacitor *stores* a substance which reaches it through the wires. I'll call that substance "electricity" until a precise technical term seems desirable. Students also nearly always intuit that *the capacitor returns to its original condition* after each cycle of charging and discharging. I'll indicate a little later on how this valid preconception of reversibility of capacitor functioning can be exploited to deal with the issue of absorption *versus* conservation during bulb lighting, that is, with the choice of catcher model or friction model.

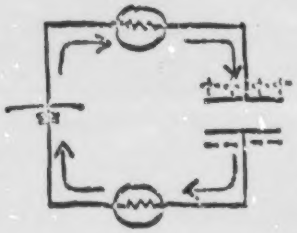
Of immediate interest is the fact that bulb lighting during capacitor charging constitutes evidence of failure of the sink model. Though each of the two posited substances emitted by the battery can reach one of the bulbs, and perhaps pass through and build up in one of the capacitor plates, it is impossible for the two substances to come together in the filament of either bulb. Therefore, the sink model falsely predicts that the bulbs should remain turned off during capacitor charging.



Before trying to decide between the catcher and friction models of bulb lighting, it is useful to resolve an important issue raised by the circuital flow pattern which these models share. The question is: Where does the electricity that flows through the wires originate?

Experience with circuits of batteries and light bulbs alone suggests to many students that batteries are the sole sources of this mobile substance. However, the presence of the capacitor in the circuit we are looking at here offers a compelling suggestion that electricity originates in passive conducting matter as well as in batteries.

Consider the geometrical constraints imposed by the presence of the capacitor. Though the electricity passing through the upper bulb in this diagram may naturally be supposed to come from the battery, the electricity passing through the lower bulb appears rather obviously to be coming from the lower capacitor plate. But that implies prior existence in the lower plate, and thus depletion of a normal constituent of that plate.



MUST HAVE DEPLETION
IN ONE PLATE

Accordingly, I have placed (-) signs by the lower plate to indicate the presence of less than the normal amount of this intrinsic substance when the capacitor is charged. The (+) signs by the upper plate indicate the presence of more than the normal amount, resulting from passage through the upper bulb.

In trying to decide between the catcher model and the friction model of bulb lighting, it is now essential to assume that mobile electricity is a normal constituent of metallic materials as well as of batteries. This conception provides a clear physical picture of what is meant by a capacitor being "charged" and then "returning to normal". With such a picture in mind, it becomes possible to attack the catcher model by demonstrating that absorption of the mobile substance in lighted bulbs cannot be reconciled with capacitors returning to normal after a cycle of charging and discharging.

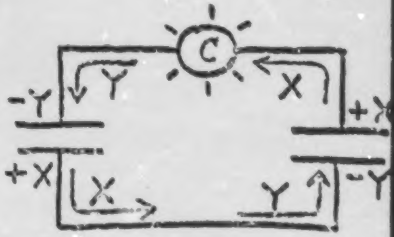
Assume that the two capacitors shown here were charged in the same manner, with an amount X of electricity being added to one plate of each capacitor and an amount Y removed from the other plate. Assume further that the bulb "catches" an amount C during subsequent discharging.

The conditions for the capacitor to return to normal as a consequence of discharging are $Y=X-C$ by the upper path and $Y=X$ by the lower path. Note that these dual requirements can be satisfied only if $C=0$. Thus they imply that the catcher model of bulb lighting is not compatible with reversibility of capacitor charging.

UPPER PATH: $Y=X-C$

LOWER PATH: $Y=X$

$\therefore C=0$



One must therefore choose between the catcher model without reversibility of capacitor charging and the friction model with reversibility. I feel it is helpful for students to become clear early on about this constraint on the available choices. It brings their spontaneous conviction about reversibility of capacitor charging to bear on the choice of an appropriate model of bulb lighting, and reduces the time required to come to a decision.

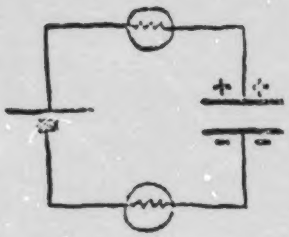
I also feel it is helpful to acknowledge and confirm students' belief that *something* really is being transferred irreversibly from batteries to lighted bulbs, to give that something the name "energy", and to indicate that the energy used up in bulb lighting is something quite different from the mobile electricity moving through the wires. The energy originates *only in the battery*, as students intuit, while the mobile electricity originates in metallic materials as well as in batteries. Electricity is transported through the connecting wires, while the mode of transport of energy remains obscure.

I am indebted to Elsa Feher for pointing out in correspondence that students' belief in "electricity" being used up during bulb lighting can be more usefully regarded as a valid preconception about energy than as a misconception about electric charge. Since beginners cannot possibly imagine a Poynting-vector description of energy transport, it is only natural for them to imagine transport as occuring through the connecting wires. This perspective suggests to me that we may be dealing here with confusion about the mode of energy transport rather than with a profound misconception about non-conservation of electric charge. I think we could use some research on this issue -- and some pedagogical imagination.

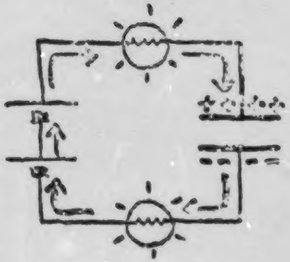
A COMPRESSED AIR CAUSAL MODEL

To generate an intuitive conception of electric potential at this point, one need only ask: Why is capacitor charging transient? Why is the charging process self-limiting? Two simple explanations come to mind, one involving a passive conception of electricity and the other an active conception.

The passive explanation holds that one capacitor plate becomes filled up with electricity and is then unable to take in any more, and/or that the other plate becomes empty and can't give up any more. Many students believe at first in this explanation. Their belief may be challenged by adding a second battery in series after charging by the first one has stopped. The observed renewal of transient bulb lighting is readily interpreted as indicating that the capacitor is becoming charged more fully. This experiment demonstrates that the capacitor plates were neither full nor empty, and effectively lays the passive explanation to rest.



AFTER CHARGING



EXTRA BATTERY

An active explanation, however, which assumes that mobile electricity behaves like compressed air, offers a quite reasonable explanation of the result of adding the second battery: The stronger pumping action provided by two batteries produces additional compression and rarefaction in the capacitor plates, accompanied by renewed bulb lighting while additional electricity is in transit from one plate to the other. But the increasing compression of mobile electricity in one plate of the capacitor arouses increasingly stronger opposition to further compression. The force of opposition eventually becomes strong enough to stop the charging process again, and again to bring passage through the bulbs to a halt.

The most powerful evidence that an active explanation is needed comes from observation of capacitor *dis*charging. Here, the question arises: Why does compressed electricity return from sites of buildup to sites of depletion? Why doesn't it just stay where it was left at the end of the charging process?

The concrete experience of bulb lighting *without any battery present* makes it very clear that some sort of *non*-battery causality must be operating in the circuit. The compressed air metaphor now provides students with a compelling causal model and fosters a conception of electric potential as *a pressure-like condition* in a compressible distribution of electricity.

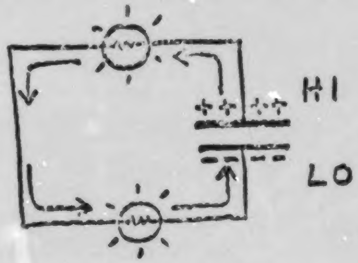
Here is the explanation of capacitor discharging that I have seen develop spontaneously in college and high school classes:

(a) "Electric pressure" exists as a condition in the mobile electricity found in conducting matter, just as "air pressure" exists as a condition in the air found in containers.

(b) Electricity *pushes* itself away from sites of high electric pressure and toward sites of low, just as air pushes itself from sites of high to sites of low air pressure.

(c) As with air pressure, only a *difference* of electric pressure between two space points can cause displacement of electricity from one point toward the other.

EXPLANATION OF DISCHARGING:



I would like to pause at this juncture to share with you my dilemma regarding use of the compressed air analogy.

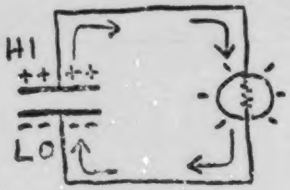
On the one hand, I have ample evidence from classroom experience that beginning students adopt the electric pressure idea with enthusiasm, and that they find it very useful for reasoning about electric circuits. Moreover, as I shall demonstrate later on, the overgeneralization which is built into the compressed air metaphor may be subsequently exploited to reveal its own limitations and to motivate introduction of the standard model of electrical causality employed by experts. Thus the compressed air analogy may be regarded as an intermediate model, whose function is to provide an intuitive stepping stone to a more abstract conception.

On the other hand, I have found that this particular intermediate model often encounters resistance -- of the human, non-electrical, kind! There is opposition to using non-standard terminology, to borrowing the "pressure" concept from fluid mechanics and to teaching a "wrong" model. I look forward to hearing about the problems this audience perceives in the implementation of my approach.

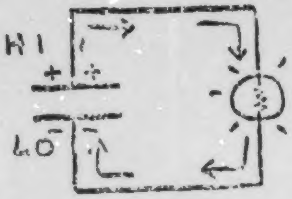
PROPERTIES OF RESISTORS AND WIRES

When the idea of electric pressure has become reasonably secure, it becomes possible to think with precision about the properties of circuit elements.

The resistance concept may be generated by connecting identically charged capacitors to non-identical light bulbs, in order to associate different relaxation times with different bulbs. Nonpolar capacitors with sufficient capacitance for this purpose (in the range 0.1 to 1.0 Farad) are available commercially as back-up energy sources for computer memory.



BULB "A":
LONG TIME



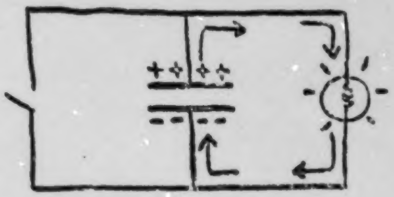
BULB "B":
SHORT TIME

Students intuitively take the observation of bulbs with longer and shorter discharge times as evidence that the former bulb is "harder to get through" than the latter. Thus:

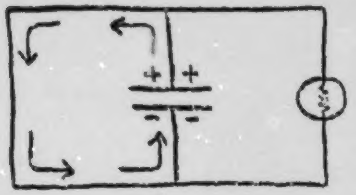
(a) Light bulb filaments "resist" the flow of electricity through themselves (because of friction). They have a resistance property.

(b) The filament of bulb A resists "harder" than that of bulb B (because of stronger friction). Bulb A has more resistance than bulb B.

A modification of this experiment demonstrates that connecting wires have negligible resistance compared to light bulb filaments. Connect a shorting wire to a capacitor that is discharging at a leisurely rate through a bulb. Students readily interpret the observation of *sudden* turn-off of the bulb as evidence that the wire provides a *super-easy* path through which the capacitor discharges in a negligible amount of time.



LEISURELY



SUDDEN

One may employ this zero-resistance property of wires to establish the *equipotential* property. Since the latter property plays such a useful role in circuit analysis, it is important to emphasize that negligible resistance means:

(a) A wire cannot sustain a difference of electric pressure for a significant length of time.

(b) Therefore, a wire will always be found to have a *uniform electric pressure value*.

(c) This value may change to a *different uniform value* when an external parameter is varied.

To comprehend this equipotential property requires a view of wires as active, and even *hyper*-active, electrostatic devices. The inability of wires to resist internal motion permits the mobile electricity present in them to react with great vigor to changes of external circuit parameters, resulting in practically instantaneous relaxation of internal electric pressure differences.

In my experience, students find the electric pressure concept very helpful for thinking about the equipotential property of wires and the consequencies of that property. Without the compressed air analogy, it becomes difficult for them to imagine that ordinary wires -- which superficially don't seem to do very much -- are in fact active circuit elements that strive to maintain uniform electric pressure values. Without this intermediate model one risks a retention of the preconceptual idea, as observed in the interviews of Fredette and Clement,[2] that wires are merely propertyless conduits.

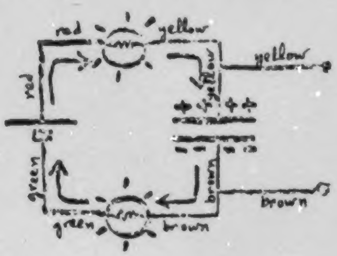
COLOR CODING AND GLOBAL REASONING

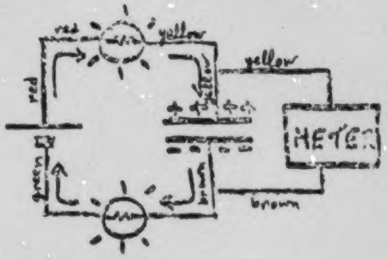
The fact that different wires in a circuit may have different uniform electric pressure values suggests the utility of color-coding the wires of circuit diagrams for values of the electric pressure. Students regard color coding as an exceptionally valuable procedure, and the research of Cohen, Eylon and Ganiel has made it clear to me why this is so. In their words: "Students have difficulties in analyzing the effect which a change in one component has on the rest of the circuit.... The results indicate that many students are unable to consider both the global and local changes, and they stick to a local analysis."

The usefulness of color coding lies in its ability to knit local information together into a global pattern. It provides an ever-present reminder that local information is embedded in a global context, and that local changes will have global consequences. Here are a few illustrations. (I'll use the term "voltage" to connote a difference of electric pressure between two points.)

In the case of voltage measurement the two connecting wires needed for a meter may be identified as adopting the electric pressure values associated with their contact points on

the circuit which is to be diagnosed. Connecting the meter then invites the difference of these two values to act on the meter, and the meter to respond to that difference. Of course, the meter should have very large resistance if its introduction is intended to have a negligible effect on the distribution of electric pressure values in the circuit.





There are four circuit diagrams here in which the use of color coding provides an answer to a possibly troublesome question regarding voltage distribution.

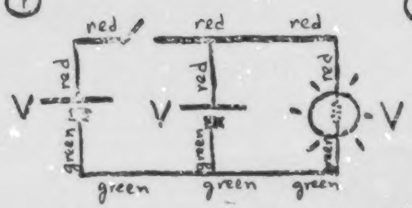
(1) In the first diagram it explains why adding a second battery in parallel may have no effect on bulb brightness.

(2) In the second diagram it explains why adding a second battery in series has a profound effect on bulb brightness.

(3) In the third diagram it explains why the addition of another connecting wire may have no effect on bulb brightness.

(4) In the fourth diagram it explains why short-circuiting a lighted bulb causes it to turn off and remain off.

①


red
red
red
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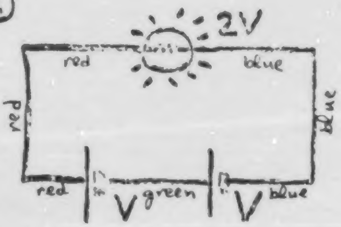
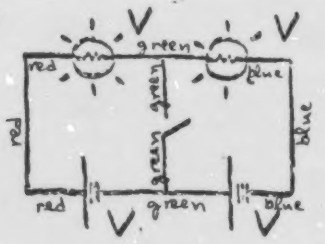
red
red
V
V
V
green
green
green
green
green
green

②


2V
red
blue
red
blue
red
V
green
V
blue

③


V
V
red
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blue
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red
blue
green
red
green
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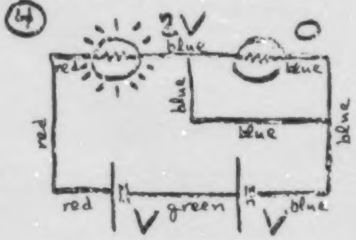
V
V

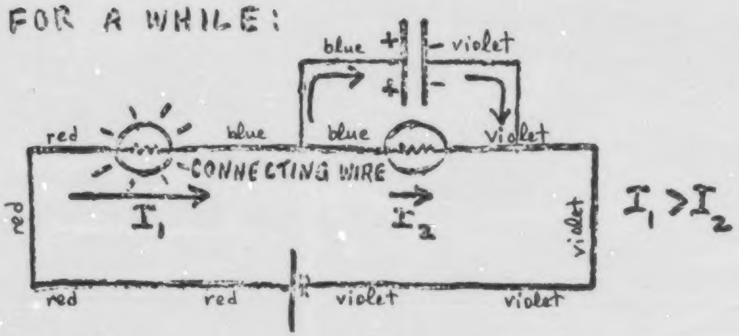
④

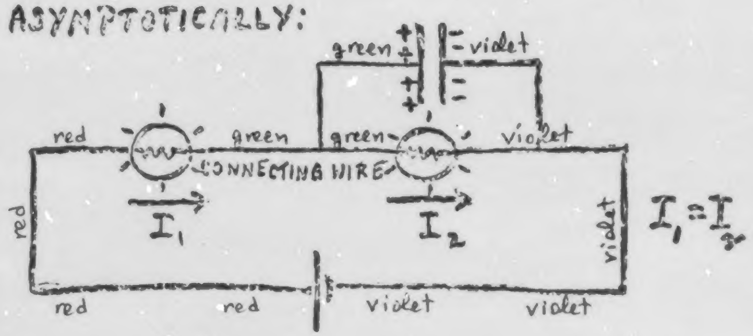

2V
0
red
blue
blue
blue
red
blue
blue
red
V
green
V
blue

CURRENT CONTINUITY

Color coding can also help clarify the question of current continuity in series-connected resistors. As Van Zee, Evans, Greenberg and McDermott [3] have shown, current continuity is often a vexing issue even for students who have had instruction in college physics courses. For some, the problem is linked in an obvious way to use of the catcher model of bulb lighting. For others, however, it could also arise from lack of insight into the causal *necessity* for current continuity. That necessity is a consequence of global self-regulation of electric pressure differences.

The time scale for self-regulation may be stretched out enough to experience it concretely. It is only necessary to recognize that *a resistor and the wires attached to it constitute a leaky capacitor*, and to make the capacitance value enormously larger by adding a non-leaky exogenous capacitor in parallel. The effect is most dramatic with non-identical light bulbs, when the capacitor is connected across the bulb having the greater resistance.


FOR A WHILE:
blue
+
-
violet
+
-
red
blue
blue
violet
CONNECTING WIRE
I₁
I₂
red
violet
I₁ > I₂
red
red
violet
violet


ASYMPTOTICALLY:
green
+
-
violet
red
green
green
violet
CONNECTING WIRE
I₁
I₂
red
violet
I₁ = I₂
red
red
violet
violet

There are two points to be made here. The first of these is that there is in fact more current through one of the bulbs than through the other -- for a while. Thus we really *don't* have current continuity, in an important sense, during the time required for electric pressure differences to relax to their equilibrium values. The second point is that strict current continuity is indeed necessary, as an *asymptotic* condition, when the distribution of electric pressure values finally reaches global equilibrium. These are subtle but instructive predictions of the compressed air model of electrical causality.

This raises an issue which may merit some research: The difficulty many students have applying current continuity to steady-state circuits could arise from this principle being presented to them as valid *at all times*. Such an interpretation would correspond to flow with no spatial redstribution whatever, which could violate fundamental feelings about the way distributed matter behaves. I have been repeatedly struck by the new-found ease students feel in applying current continuity to problems involving a change of parameter, once they realize they are being asked to describe a new *final equilibrium* state and should ignore the period of transition during which that state is achieved.

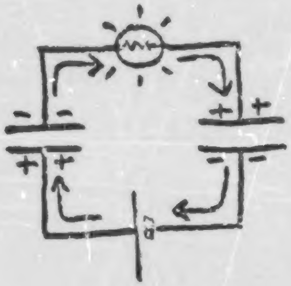
I suggest it would be a worthwhile exercise for students to articulate *why* a circuit will eventually reach a condition of global equilibrium, characterized by current continuity for series-connected resistors, starting from a condition of non-equilibrium. As illustrated here, time-varying color coding of the wire connecting two resistors may be combined with reasoning based on the compressed air analogy to coordinate voltage changes across the resistors.

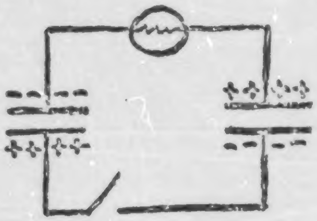
Consider: If there ever happens to be greater inflow than outflow to the connecting wire that joins the resistors, the result will be a growing electric pressure value in that wire -- say, from blue toward green. This growth reduces the voltage across the resistor that controls inflow to the connecting wire, and raises the voltage across the resistor that controls outflow from the wire. The effect of both voltage changes will be to decrease the rate of inflow to the connecting wire and to increase the rate of outflow, resulting in a *reduced rate of growth* of the electric pressure value in the connecting wire. The asymptotic limit of this process will be a stable quilibrium characterized by equality of the currents through the two resistors.

GENERALIZATION TO A MORE ADEQUATE CAUSAL MODEL

Electric pressure is a useful concept only in a circuit of contiguous conducting matter, where it makes sense to think of electricity as acting on itself by means of *contact* forces. I suspect that the power of this concept may be rooted in the fact, reported by Piaget [4], that the ability to reason about transmission phenomena develops earliest in the domain of mechanical contact interaction.

Now, note that contiguity of conducting matter is broken in circuits containing capacitors connected in series, so that use of the electric pressure concept becomes problematic. I propose to exploit such circuits to demonstrate the *limitations* of the compressed air analogy and to shape a more adequate causal model. Though this would seem to require a more advanced level of causal reasoning, one may hope that experience with the compressed air model has developed some readiness for the occasion. I have found the following circuit useful for this purpose.


WHY IS THIS BULB ON?


WHY IS THIS BULB OFF?

Note first of all that the bulb in this circuit lights up during charging and discharging of the capacitors. even though there is no conducting path by which electricity can reach it from the battery. Anything passing into and out of the bulb through the wires must come from and return to the metallic material of the upper half circuit. There is compelling confirmation here of some previous inferences:

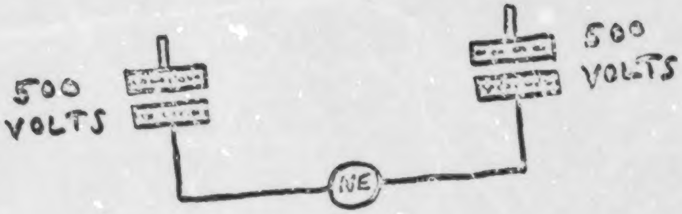
(a) Mobile electricity is present everywhere in conducting matter.

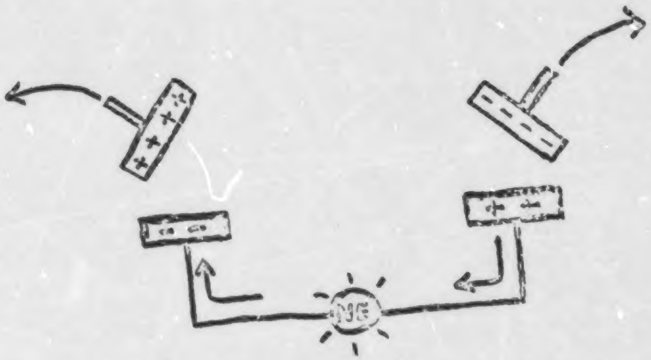
(b) Electricity is not used up by the process of bulb lighting.

But experimentation with this circuit also brings with it recognition that *the compressed air model is not adequate to explain the whole range of circuit phenomena*.

During the charging process, it seems clear that electricity is being pushed out of the plates marked (-) without any possibility of being acted on by contact forces. This implies that *action-at-a-distance forces*, rather than contact forces, repel electricity away from the plates marked (+). After the battery is removed, moreover, but before the circuit is reconnected to permit discharging, it appears that the sites marked (-) and those marked (+) are holding each other in place. This suggests that the sites marked (-) are active concentrations of *a second kind of electricity*, rather than sites of depletion of a single kind, and that the two kinds attract each other.

Action-at-a-distance *attraction* can be proved with a pair of large demonstration capacitors, a Neon bulb and a battery of several hundred volts. When the capacitors are charged and in place, lift the upper plates deftly away and watch the Neon bulb light up. This is evidence that the electricity on each of the lower plates was formerly being attracted and held in place by electricity of the other kind on the corresponding upper plate.





Experiments such as these create the need for a model of electrical causality that is richer in possibilities than the compressed air model. I see them functioning in support of a cognitive process which has been described by Karmiloff-Smith and Inhelder,[5] who argue that the construction of false theories or the overgeneralization of partially valid ones can make believers vulnerable to the experience of surprise and thereby predispose them to productive leaps of imagination. The leap required here is, of course, to a causal model embodying two new ingredients:

(a) long range forces, to coordinate electric pressure values in non-contiguous conductors, and

(b) two types of electricity, to account for attractive as well as repulsive interaction.

This is the point at which I feel it is useful to change terminology from "electricity" to "electric charge" and from "electric pressure" to "electric potential". This juncture also seems the appropriate moment for introducing traditional experiments in macroscopic electrostatics, and for discovering the presence of *bound* charge in insulating materials together with the dielectric property of those materials.

It is now a straightforward technical procedure to construct the familiar electrostatic field model, including a generalized conception of electric potential as *a condition in space* which exists in insulating matter and vacuum as well as at sites occupied by mobile electric charge. That procedure builds directly upon an intuitive foundation supplied by the compressed air model of electrical causality. Since it has little to do with overcoming misconceptions, however, this seems an appropriate place for me to stop.

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2. Norman Fredette and John Clement, *J. Coll. Sci. Teach.* 18 (1980): 194.

3. Emily van Zee et al., AAPT meeting in San Francisco, Jan. 27, 1982.

4. Jean Piaget, *Understanding Causality*, W. W. Norton and Co. (New York, 1974).

5. Annette Karmiloff-Smith and Bärbel Inhelder, *Cognition* 3 (1974/75): 195.

An Examination of Student Inconsistencies in Their Understanding of Trajectory Motion

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Southwest Missouri State University

The responses of college physics students to six questions on trajectory motion were recently reported (Whitaker, 1983). (A list of these questions is given in the Appendix.) A comparison of those students enrolled in a calculus level course with those in a trigonometry level course did not reveal any major difference in the responses to the questions or the reasons given for the responses. Similarly, while a larger percentage of students, who had studied high school physics, responded "correctly" to the questions, the consistency of their responses to similar questions and the reasons for their responses was not as large as one might expect. This paper will examine those reasons given by the entire group of students who responded "correctly" to these questions.

Table 1 summarizes the responses of all of the students who participated in the study. Questions 2, 5, and 6 are similar questions: an object falls with respect to a reference system that is moving at a constant velocity along a straight line. Questions 3 and 4 refer to two objects, one of which is released to fall vertically from rest at the same instant that a second object is given a horizontal velocity.

Examination of the responses in Table 1 reveals considerable variation in the responses of students to similar questions. Of these students, only 25 answered all three of the first group of questions "correctly," and 37 answered both of the second group "correctly."

More revealing than the answers to the questions, however, is the reason that students gave for their responses. Even those students who selected the "correct" answer for the question did not always give "correct" reasons for their choice. Table 2 summarizes the reasons that students gave for "correct" answers to each of the questions. The reasons given for each of the two sets of similar questions also show inconsistencies. Following are some of the reasons which students gave for each of the "correct" responses to the questions.

Student Reasons for "Correct" Responses

1-C. Newton's Law

Galileo's Law

Gravity acts the same. [Marked "correct"]

Because gravity is a constant force.

Because the force of gravity is the same on each needless of the weight.

Gravity pulls things toward it at the same speed.

They fell at the same speed.

Everything falls at the same speed.

Because equal amounts of force (compared to its weight) are being exerted against the balls, so that neither can get any faster than the other.

The difference in their mass is small compared with that of the earth so that there is no difference in the way gravity affects them. Hence they accelerate with the same g.

The force of g is the same on each ball, but it will take longer for the 50 lb. ball to speed up.

It will hit at the same time because once the balls reach a point where the gravitational pull equals the upward wind force, the objects will fall at the same speed. I think surface area of the objects probably has something to do with it.

2-B. Because I think something like the laws of inertia and the velocity at which the train is traveling.

The speed of the train forces the bolt to move "backwards" as it falls, but it actually does not. -- It depends on your viewpoint.

The bullet [?] is traveling at the same forward speed as the train; the distance it has to fall is short enough that it won't be significantly affected by gravity.

Guess.

3-B. Both objects accelerate downward at the same velocity. Motions in horizontal and vertical directions are independent of each other. [Marked "correct." Other questions showed "correct" answers or "same as above."]

Gravity pulls all mass down at the same rate no matter of what its side ways force.

My brother told me this story before. [Marked "correct."]

Because the bullet has a higher speed, it will travel a horizontal distance until it loses momentum enough to fall to earth, and hit when the ball does.

While the bullet accelerated forward, the force of gravity pulls it down at the same rate as the ball and, since the distance is negligible, they should hit the ground at the same time. I would assume similar weights.

This may depend on the velocity of the bullet.

Because of the difference in velocity and the pull of gravity.

The ball and bullet will both travel towards the earth's gravity at the same speed regardless of weight or propulsion.

Because the force of gravity is constant.

They both have the same gravitational pull.

4-B. If the muzzle velocity of the bullet is sufficient, then the speed of the bullet to its target will be greater than the acceleration of the monkey, the falling body.

The bullet travels faster than the monkey falls.

The horizontal path of the bullet is moving toward the monkey at a much faster rate than the monkey would be falling.

Assuming a fall of the trajectory of the bullet, the bullet should hit said monkey before it has time to drop far enough. [All other questions were "correct" with good reasons.]

It seems as if the bullet will have enough velocity to reach the monkey before he falls.

Monkeys are slow.

Bullet speed is faster than reaction time of monkey.

Depends on speed of bullet.

The monkey isn't as heavy as the ball in Question 3. [Which was answered incorrectly.]

It takes a relatively longer period of time for the acceleration of the monkey to pick up and bring it toward the ground than the acceleration of the bullet.

It could depend on whether the gun was aimed at the monkey's head or feet and how far away the gun is from the tree.

Probably, but may depend on where the bullet was aimed specifically on the monkey.

The bullet has a force to it which makes it quicker than the gravitation fall.

5-B. It will tend to travel in the same direction it was going before it will hit the ground. Since the horse can't travel at great speeds the ball will probably drop in about the same place as where it was dropped. [All but Question 3 were "correct."]

The forward motion of the rider will carry the ball forward. [All other answers "correct."]

The ball and the horse and rider have the same momentum.

The ball and rider are going at the same speed when the rider lets go of the ball. Its potential will push the ball until a force stops it. Like the ground.

6-A. The ball has the same momentum forward as the boat does causing it to strike at the foot of the mast.

As in Questions 2 and 5 [which looked at "changing forward momentum"] -- a combination of forces.

The ball and boat are together so their momentum is together.

Discussion

A study of these reasons, which were given to "correct" responses to the questions, reveals that many students give reasons that are similar to those that were given to "incorrect" responses. While the largest number of students answered Question 1 "correctly," a relatively large number of these showed confusion about the difference between speed and acceleration. Another reason that was given for this question, and one that appears in later questions, is that the "force of gravity" on all objects is the same. Students have heard words like "gravity," but they have not yet organized the concept in a consistent and accurate way.

The idea of an "impressed force" is still strong among those who answered the other questions "correctly." Similarly, confusion regarding the vector nature of velocity, displacement, and acceleration is clear in the answers given by a number of students.

"Correct" answers were given to the "hunter and monkey" problem (Question 4) by 61% of the students. However only 51% of the reasons given by these students were also "correct." In addition to the reasons given above, students seem to provide additional information to this problem. Several imply good marksmanship on the part of the hunter. Others imply that the monkey acts upon seeing the hunter fire, thus delaying his fall through his reaction time. However, these reasons also imply that the path of the bullet is relatively horizontal until it hits the monkey.

McCloskey (1983) has recently published findings of another study, which also included students' understandings of trajectory motion. The findings reported above are consistent with his study. He also observed the difficulties that students have in modifying their intuitive ideas about motion even after completing a course in physics. He noted that "The instruction was particularly unsuccessful in altering the core assumption that impetus acquired when an object is set in motion serves to maintain the motion . . ." (p. 130).

Following instruction on kinematics in a trigonometry based college physics course, in which the questions reported in this study were used as an introduction to trajectory motion and were discussed prior to an algebraic treatment of the topic, this author has asked as a quiz question the problem in Figure 1. While detailed data have not been collected on the results of students' answers, only about 50% have answered this question correctly. Students, who indicate that the object following path "C" will strike the ground first, give the reason that it has the higher velocity when it leaves the table. Those, who state that the object following path "A" will strike the ground first, give the reason that it has a shorter distance to travel. Many of these students answer numerical problems, involving similar concepts, correctly on the same quiz.

"Correct" answers to problem sets or examination questions may serve to mask student understanding of the concepts involved. The ability to manipulate an algebraic equation to arrive at an acceptable answer may not be the same as a qualitative understanding of the concept(s) the equation is intended to represent. Arons (1982) has recently provided us with evidence that these may not be the same thing. Resnick (1983) has also pointed out the importance of confronting students with their own understandings of phenomenon as a beginning point for more formal instruction. This is a time consuming task for both the student and the instructor, but it is one that needs to be taken into account in our continuing search for improved instruction and student understanding.

APPENDIX[a]

1. A 5 pound ball and a 50 pound ball are dropped from the roof of the building. Each ball is the same size, that is, it has the same diameter. The 50 pound ball will hit the ground
   A. sooner than the 5 pound ball.
   B. later than the 5 pound ball.
   C. at the same time as the 5 pound ball.

2. A train is traveling along a smooth, straight track at a speed of 60 miles per hour. One of the boxcars has a small hole in the floor. Directly above the hole is a bolt in the ceiling. Suddenly the bolt comes loose and falls. The bolt will
   A. hit the floor in front of the hole.
   B. fall through the hole.
   C. hit the floor in back of the hole.

3. A rifle is mounted so that its barrel is horizontal and is pointed across a long, flat field. A heavy ball is placed at exactly the same level as the muzzle of the rifle. The gun is fired and at the same time that the bullet leaves the end of the barrel, the ball begins to fall straight down. The ball will hit the ground
   A. sooner than the bullet.
   B. at the same time as the bullet.
   C. later than the bullet.

4. A rifle is mounted so that its barrel is horizontal and is pointed straight at a monkey in a tree. The rifle is fired at the monkey and at the same time that the bullet leaves the end of the barrel, the monkey drops from the tree toward the ground. The bullet will
   A. pass over the monkey's head.
   B. hit the monkey.
   C. pass below the monkey.

5. A rider on a galloping horse holds a heavy ball out to his side and drops it. The ball will hit the ground
   A. immediately below the point where it was dropped.
   B. immediately below the point the horse and rider are when the ball reaches the ground.
   C. some position other than A or B. Please specify.

6. A boat is sailing rapidly along the surface of a smooth lake. A heavy ball is dropped from the top of a high mast. The ball will fall and
   A. strike the deck at the foot of the mast.
   B. strike the deck behind the foot of the mast depending on the speed of the boat.
   C. strike the deck in front of the mast depending on the speed of the boat.

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[a] Published in Whitaker, R.J. Aristotle is not dead: Student understanding of trajectory motion. American Journal of Physics, 1983, 51, 365-366.

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McCloskey, M. Intuitive Physics. Scientific American, 1983, 248, 122-130.

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Whitaker, R.J. Aristotle is not dead: Student understanding of trajectory motion. American Journal of Physics, 1983, 51, 352-357.

Table 1. Responses of all students to questions on trajectory motion (N = 100).

Answer	A	B	C	No answer	More information needed
Question					
1	22	0	78[a]	0	0
2	1	60[a]	37	2	0
3	38	55[a]	7	0	0
4	30	61[a]	1	1	7
5	21	33[a]	43	3	0
6	39[a]	55	1	5	0

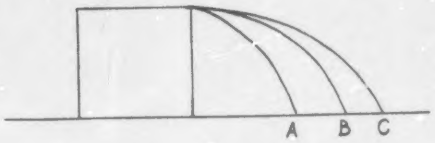
[a] "Correct" responses.

Table 2. Summary of reasons given by students who selected the "correct" answer to questions on trajectory motion.

Question-Answer	No. of "Correct" Answers	"Correct" Reason	Incomplete or "Incorrect" Reason	No Reason Given
1-C	78	58 (74%)	17 (22%)	3 (4%)
2-B	60	53 (88%)	9 (8%)	2 (3%)
3-B	55	43 (78%)	11 (20%)	1 (2%)
4-B	61	31 (51%)	27 (44%)	3 (5%)
5-B	33	23 (70%)	6 (18%)	4 (12%)
6-A	39	35 (90%)	3 (8%)	1 (2%)

Figure 1. Example Quiz Question on Trajectory Motion

A ball rolls off a table with different speeds and follows the trajectories shown here. Neglecting air friction, compare the times between leaving the table and hitting the floor for the three paths. Clearly explain your reason(s) for your answer in order to receive credit.



Amino Acids and Translation:
A Misconception in Biology

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Davis

INTRODUCTION

A variety of "alternative conceptions" have been observed among students of mathematics and physics. Some alternative conceptions, judged to be erroneous ideas or misconceptions, have the following characteristics.

1. They are at variance with the conceptions held by experts in the field.

2. A single misconception, or a small number of misconceptions, tend to be pervasive; that is, they are shared by many different individuals.

3. Misconceptions range across a spectrum from relatively easy to relatively difficult to change. Many are highly resistant to change or alteration, at least by traditional teaching methods.

4. Misconceptions sometimes involve alternative belief systems comprised of logically linked sets of propositions, and they tend to be used by students in systematic ways (e.g., the impetus theory of motion).

5. Some misconceptions have historical precedence; that is, erroneous ideas put forth by students today mirror ideas espoused by early leaders in the field, such as Aristotle or Galileo (Champagne et al., 1982; Clement, 1981).

On the bases of these general characteristics, in conjunction with the specific attributes of particular misconceptions, certain inferences have been drawn. Some of these are summarized below.

1. With respect to the their ORIGINS, it has been suggested that misconceptions...

a) may in some instances arise as a function of the neurological 'hardware' or genetic programming (as has been suggested, for example, for language structures, which may be automatically invoked when "reading" an equation).

b) may be acquired through certain experiences that are commonly shared by many individuals (as with moving objects), especially when influencing variables mask the concept to be understood (as in the effect of friction on moving objects, which makes it difficult to intuitively grasp Newton's first law).

c) may be acquired through instruction in school or other settings.

2. With respect to their UTILITY, it is suggested that misconceptions serve the needs of the persons who hold them reasonably well, as in...

a) minimizing the information processing load, or

b) permitting (not preventing) various performance goals (e.g., it may be possible to catch a ball while harboring erroneous ideas about the ball's precise trajectory), or

b) permitting (not preventing) systematic thought about a topic (e.g., one may correctly anticipate that it will rain even while having vague or wrong ideas about how rain clouds form).

3. With respect to their PERSISTENCE, it is often suggested that misconceptions are "deep-seated" as a consequence of...

a) being frequently reinforced.

b) being well "connected" to other nodes in the knowledge framework (semantic network).

c) having been acquired relatively early in life.

In this paper I describe a misconception concerning molecular biology that brings some of these inferences into question. Molecular reactions are an intrinsic part of each of us, but they are largely or entirely invisible. We do not build up a store of conscious experience with regard to them as we do with moving objects in the physical world. Nor do we receive instruction about them over a period of years as is the case with mathematics. Yet we see in our students, quarter after quarter, a persistent misunderstanding that seems to have all the characteristics associated with misconceptions: it is widely shared, systematic, and resistant to change.

THE MISCONCEPTION: AMINO ACIDS AND PROTEIN SYNTHESIS

Protein synthesis involves two major processes. In the first, transcription, information is copied from one or more genes (DNA) to a messenger RNA molecule. In the second, translation, the information is converted from the linear array of nucleotide bases (adenine, guanine, cytosine, and uracil) in messenger RNA to a corresponding linear array of about 20 amino acids in a polypeptide. A single polypeptide may become (usually with some minor modifications) a biologically active protein, or two or more polypeptide chains may be united to form a biologically active protein. Thus, it is correct to say that polypeptides or proteins are the products of translation.

We first became aware of students' difficulty with this concept about ten years ago, when my colleague, Dr. Richard Snow, placed the following item in our test item bank:

> Which of the following molecules are products of translation?
> A. Amino acids
> B. Transfer RNA's
> C. Activating enzymes
> D. Messenger RNA's

When this question was first asked (in 1972-73) in an upper division introductory genetics course for science majors, about 55% of the students chose the correct answer, "activating enzymes". Most of the remaining 45% chose "amino acids."

The proportion of students who were able to correctly answer this seemingly simple question remained stubbornly persistent over the years, even as we a) tried to address the problem in our presentations of the material, b) changed textbooks, and c) changed instructors. Given the difficulty in maintaining a particular instructional outcome in the face of such global changesin instruction, the persistence of this error is surprising.

For example, of 271 students who received that question on their final examination in introductory genetics in 1976, 55.7% (151 students) answered correctly. The incorrect answer, "amino acids", was chosen by 35.8% (97 students) and the other two incorrect answer choices were selected by 8.5% (23 students). Similarly, in 1977, 50% of the students in an introductory genetics class answered the question correctly.

The question sometimes bothers students. Often after an exam one or two students will say, "That's a bad question. amino acids aren't really products of translation - they take part in the reaction." When I respond, "I know. Why did you choose that answer?", they look utterly dumbfounded. It hasn't occurred to them that "amino acids" may not be the correct answer! Many such informal discussions suggest that virtually all genetics students know the individual facts that 1) translation is part of protein synthesis, 2) protein synthesis produces proteins, 3) enzymes are proteins, and 4) activating enzymes are enzymes -- yet many don't answer the question correctly. Although they seem to have the individual pieces of information, they apparently haven't made the necessary connections, or don't have the information organized in a meaningful, manageable way, as in a runnable model. In information processing terms, they haven't formed a correct and coherent schema.

Students enrolled in the lower division introductory biology course for science majors (typically taken by sophomores) exhibit the same error with even greater frequency -- on the average, 75% answer the question incorrectly. The majority choose "amino acids" but "messenger RNA" is also a

popular choice, indicating greater confusion between transcription and translation at this level.

HYPOTHESES: UNDERLYING COGNITIVE MECHANISMS

Thus far, attempts to help students avoid this pitfall (to teach more effectively) have been notably unsuccessful. As noted, the error persists at about the same rate among many different classes of students with many different teachers and a variety of textbooks. It seems necessary to understand the mental mechanism(s) responsible for producing the error in order to successfully take corrective action.

Norman (1981) suggests that cognitive errors typically have multiple causes. Slips of the tongue, for instance, do not lead to the insertion of any randomly selected word in a person's vocabulary into a sentence, but one particular word is substituted for another, due to a situation-specific combination of internal and external events.

It may be useful, therefore, to consider attributes and possible causes of the "amino acids" error and to examine the empirical evidence for them. Examination of classes of students provides a fairly robust analysis of the relative contributions of various causal factors within populations. Interviews with individuals provide insights about the difficulties of individual students. Both types of evidence are described below.

Hypothesis 1. The "misconception" was acquired very recently, perhaps in the context of the *introductory biology class.*

As noted above, students do not directly "experience" molecular biology and presumably do not learn about it very early or very often. Students in a recent biology class were asked where they had heard about or studied protein synthesis. Of 195 students, 93 said they heard about the topic for the first time in this course. The remaining 102 had heard about it previously, including 81 in high school biology; 35 in other courses at the high school, community college, or college level; 7 on television (citing NOVA and COSMOS); 11 in magazines; and 4 elsewhere (citing books, home, and Disneyland). Thus, if a three week to five year period is considered to be recent, Hypothesis 1 is accepted: all students have acquired the misconception recently, and for nearly half the student population, it has been very recent indeed.

Another line of evidence concerning the specific molecular connection between proteins and amino acids comes from a word association study. When students in elementary, junior high, high school, and college were asked to free-associate (i.e., to give the first words that pop into their minds) in response to a list of biology terms, only college students gave "amino acids" as the predominant response to the stimulus word, "proteins" (Table 1).

Hypothesis 2. There is no difference in performance between those students who hear about protein synthesis for the first time in the context of this course and those who heard about it previously.

If the misconception arose from some earlier representations of the subject, or if it became more "deep-seated" with time, then those students who heard about protein synthesis earlier would be expected to display the misconception more frequently than those students who are learning about protein synthesis for the first time in this course. On the other hand, if time span and exposure to possibly superficial representations (many students suggest that high school courses just "touch" the surface of the concept of protein synthesis) are not factors in the acquisition of a misunderstanding, one would expect the misconception to occur with equal frequency in both groups, or perhaps to be more frequent among those to whom the subject is the newest.

The question described above was presented to 55 students enrolled in introductory biology, 21 of whom had heard about protein synthesis for the first time in this course and 34 of whom had heard about it previously. Students hearing about protein synthesis for the first time scored slightly higher than those who had heard about it previously (Table 2). Opposite results were obtained with three alternative versions of the question, described under Hypothesis 6 below, that were given to the remaining 140 students in the class. Students with previous exposure to protein synthesis performed slightly better on these questions than students who were encountering protein synthesis for the first time (Table 2). Overall, the evidence supports Hypothesis 2: There is no difference in performance between those students who are learning about protein synthesis for the first time and those who heard about it previously.

> Hypothesis 3. Students develop a stronger semantic connection between "amino acids" and "translation" then they do between "proteins" and "translation." In information processing terms, "amino acids" has a higher activation level, in response to the stimulus, "translation", than does "activating enzymes", and the automatic information processing mechanisms "take over" unless they are over-ridden by conscious processing mechanisms (such as those arising from domain-specific knowledge).

Amino acids play a major role throughout the process of translation, being attached to appropriate transfer RNA molecules, being inserted into positions on the ribosome, corresponding to specific genetic code words, and so on. If repetition is one way of building a strong connection in the semantic network, then it would not be surprising if students have a strong semantic connection between "amino acids" and "translation". Proteins, on the other hand, are hardly mentioned in discussions of translation, except for occasional reference to the "growing polypeptide chain". A relatively weak association between "translation" and "proteins" would therefore not be surprising.

Evidence concerning this hypotheses is derived from a series of ten interviews with a mature, returning graduate student in the biological sciences. The student had previously completed the introductory genetics course (with a low

grade). The subject was encouraged to read, study, and do problems between sessions (although time constraints prevented extensive work). The interviews consisted of "teaching experiments" involving cycles of questioning and tutoring. Once an area of difficulty was discovered and explored through a series of questions, an attempt was made to lead the student to a more correct understanding by drawing upon practical and theoretical knowledge, familiar examples, and analogies. Each session lasted 2-3 hours, and sessions were held at weekly intervals.

In the first session, when asked to identify the product of translation, the subject at first confused transcription and translation. Once these two concepts were sorted out, the subject indicated that translation produces, as its product, amino acids. The topic was subsequently discussed at length, using diagrams drawn by the subject and illustrations in the book, to correct this error.

However, in the next session, the same response ("amino acids") was again given for the product of translation (the "misconception" is apparently resistant to one-to-one as well as classroom instruction). And again, most of this session was spent reviewing the process of translation, using not only diagrams but also a cardboard model. The model includes all twenty amino acids with corresponding transfer RNA's, and allows one, by referring to the genetic code table, to build a polypeptide step by step, according to the message contained in a cardboard messenger RNA. The subject worked through the processes involved in incorporating an amino acid into the growing polypeptide chain about five times, creating a polypeptide five amino acids long. In addition, a film about protein synthesis was viewed. This film displays a rich and imaginative (if somewhat fanciful) interpretation of protein synthesis. Thus, the concept was explored diagrammatically, verbally, kinesthetically, and visually.

In the third session, the following exchange took place:

> Interviewer (I): Where do amino acids come from?
>
> Subject (S): Well, they come out of the cytoplasm, they come, oh, okay, they come out of genetic ...yeh, translation.
>
> I: Amino acids do?
>
> S: Well you have...the genes at least code for the organization of amino acids into protein.
>
> I: The genes carry the message for linking amino acids together into protein...
>
> S: Yeh, but you're asking where the amino acids are made, where they are coming from.
>
> I: Yeh.
>
> S: Umm, I'll have to think that over...

Even after extensive instruction focusing on eliminating this misconception, the first connection made in the subject's mind was "amino acids" --- "translation." This time, however, the subject, with a prompt from the interviewer, caught his own error. This entire sequence is taken as evidence of a strong semantic association between the two words, "translation" and "amino acids".

According to Lipson (1983), this may illustrate the typical steps in correction of an error:

(1) subject isn't aware s/he is harboring an erroneous concept;

(2) subject is aware of the error when it is explained by someone else;

(3) subject makes and subsequently catches own error;

(4) subjects slips (makes error) but is aware of it instantaneously, as soon as the automatic response pops into his or her mind; and

(5) subject stops making error.

Sternberg (1977) discusses the role of word associations in the generation of cognitive errors and reviews evidence showing that it is possible but difficult to override these "automatic" responses.

These interviews are taken as evidence supporting Hypothesis 3, that there is a strong semantic connection between "amino acids" and translation.

Hypothesis 4. Students have no competing mental model concerning the production of amino acids. They typically have little or no idea about where amino acids actually do come from.

If students had a firm model of amino acid biosynthesis in mind, it would presumably be more difficult for them to assume that amino acids are produced by translation. However, relatively little attention is given to amino acid biosynthesis in most introductory biology texts; the essential amino acids (those that can't be synthesized by humans and must be ingested) are usually mentioned, and there is generally some indication that Kreb's cycle intermediates serve as precursors for amino acid synthesis. However, much more attention is paid to other aspects of amino acids. The introductory genetics course does not consider the question of where amino acids come from, and even many biochemistry textbooks seem to overlook amino acid biosynthesis.

Evidence concerning Hypothesis 4 is taken from the interviews described above. Before discussing it, it may be helpful, for non-biologists reading this paper, to include a brief review of the key biological facts at this point. (1) Amino acids are synthesized in a series of cellular reactions collectively known (along with all other cellular reactions) as metabolic pathways (metabolism refers to all biological reactions, including both synthetic and breakdown reactions). (2) Every reaction is catalyzed by a specific enzyme. (3) Every enzyme is synthesized according to information contained in the genes. (4) Genes that code for the production of all the enzymes involved in a given metabolic pathway are often clustered into groups called operons. (5) The genes in an operon are transcribed together into a polymessenger RNA which is then translated so that all the proteins (enzymes) in the group are synthesized simultaneously. (6) Humans can synthesize 12 of the 20 common amino acids and must obtain the remaining 8 through dietary sources.

The subject does not understand these relationships, as revealed in the transcript below:

> S: ...I guess I don't see why it (metabolic pathways) is a big deal in genetics.
>
> I: You don't?
>
> No, or even this operon. I don't get the connection with genetics. I don't see what the heck, why the operon is talked about in genetics? It seems more of a biochemical thing.
>
> I: OK. What do metabolic pathways make?
>
> S: Well, all that (the professor) said is that there is a final product out here. I don't have any idea of the nature of this final product.

In discussing the concepts of genetic regulation, it is customary for instructors to talk about metabolic pathways in abstract form, using E1, E2, E3, etc. to represent enzymes, I1, I2, I3, etc. (or sometimes simply boxes) to represent the intermediates, and another box labeled P to represent the end product. The subject has never made any connections between these abstract representations and any actual metabolic pathway. Furthermore, the subject does not realize that operons contain genes responsible for producing enzymes that act in metabolic pathways. Nor does the subject recognize that certain metabolic products (such as amino acids) are used in genetic processes (such as translation).

Some amino acids, as mentioned previously, cannot be synthesized by humans and must be ingested. Does the subject consider ingestion to be the major source of amino acids? In the excerpt below, the interviewer asked, what are the essential amino acids?

> S: ...the sulfur-containing ones, cystine, methionine, those are essential because we can't, somehow we can't make them, we can't synthesize them or change from one to another.
>
> I: OK, suppose we can't synthesize these. Do you know where they would come from?
>
> S: They come from your diet, but I don't see how they get into the cell.

Although the subject has the concept of essential amino acids, it is held with a certain skepticism or disbelief. How could the body possibly break down what we eat and deliver to every cell in the body the complete array of amino acids needed at any given time? As the subject pointed out:

> S: When you draw a picture of a cell, there is certainly no blood vessel running through it or anything.

The fact that human cells must have complex regulatory mechanisms for all their biological building blocks is an article of "faith" with biologists. Much of that "faith" is based upon extensive knowledge of such things as metabolic regulation in microbial systems. The student in introductory biology cannot learn everything at once, however, and s/he is necessarily hampered by lack of detailed knowledge in the domain. This may cause particular problems for students who have a low tolerance for vagueness and ambiguity.

As a further illustration of this point, 39 students in introductory biology were asked, "Where do amino acids come from?" Their responses are summarized below:

-# students	-response
-9	-synthesized in body or cell, or obtained from food
-7	-come from plants, living organisms, other amino acids, or cellular processes
-2	-from elements and molecules
-1	-primeval seas
-4	-they are (have always been) just there
-1	-they were an afterthought
-5	-don't know

-1 -no one can be completely sure

-2 -God

-7 -translation, or synthesized on the mRNA on the ribosome

About half of these answers could be considered at least partially correct, especially since the question was asked in an open-ended fashion. But it is interesting that only 9 students indicated that amino acids are synthesized in the cell or obtained from food, and 7 stated that they are produced by translation. Hypothesis 4, that most students do not have an encompassing (and correct) mental model for amino acid synthesis, is accepted. Hypothesis 4 is accepted.

Hypothesis 5. Students may be answering the question incorrectly because they are thinking of the ultimate products of translation, rather than the immediate product.

Since translation produces proteins, including enzymes, and enzymes are involved in producing all cellular components, any cellular component could be considered an ultimate product of translation. Since the question is vague on this point, not specifying "immediate", perhaps some students are making this error.

This possibility cannot be ruled out, but there is no evidence suggesting its occurrence, either. In ten years of giving this question on examinations, I have never received this argument from a student. Nor has it emerged in any conversations or interviews with students. Thus, Hypothesis 5, that students assume the question refers to the ultimate products of translation, is rejected, at least as a major source of problems. Additional research could reveal whether this error is made by a minority of students, and if so, how often

Hypothesis 6. Students will be attracted to answer choices at the level of generality most familiar to them, those which require the fewest mental steps to verify.

To answer the "product of translation" question correctly, students have to think through a logical series such as: "Translation produces proteins. Enzymes are proteins. Activating enzymes are enzymes. Therefore, activating enzymes are products of translation." Presumably most students learned the general principle (translation produces proteins), but it takes mental effort to apply the general principle to a specific instance. Moreover, in this example, some mental discipline must be required to work through this multi-step thought process to arrive at the answer, "activating enzymes", when a very familiar general class of compounds (amino acids) is available as an alternative answer choice.

To test whether the relative levels of generality and specificity of the answer choices influence the difficulty of the question, four versions of the question were presented to students in a biology class (Table 3). Approximately one-fourth of the students received each version. Two answer choices remained constant and were expressed in the most general (and most familiar) form: "mRNA's" (messenger RNA's) and "tRNA's" (transfer RNA's). The other two answer choices were varied in the four possible configurations:

general-general,
specific-specific,
general-specific, and
specific-general.

General-general. Students did best when all four answers were expressed at the most general level (amino acids, proteins, tRNA, and mRNA). Of 46 students, 59% (27) chose the correct answer, "proteins". Equal proportions (20% each) selected each of two wrong answers, "amino acids" and "mRNA".

Specific-specific. When two answers were given as specific instances, "tryptophan" (a particular amino acid) and "activating enzymes" (a particular protein), many students selected the more familiar and general but incorrect answer choices, "mRNA" and "tRNA". The question difficulty increased by about 10%, with only 47% answering this question correctly.

Specific-general. In the third version, answer choices included a specific amino acid ("tryptophan") and a more general subclass of proteins ("enzymes"). Students displayed a strong aversion to the specific answer choice, "tryptophan"; it was selected by only two of 47 students (4%). The correct answer, "enzymes", was recognized by 45%. This is a 14% lower success rate than that seen with the general-general question above, and is about equal in difficulty to the specific-specific question above.

General-specific. Finally, the last version is a reproduction of the original question, with the general "amino acids" and the specific class of proteins, "activating enzymes." The general answer, "amino acids", was selected by 38% of the 55 biology students who received this question. Only 25% selected the correct answer, "activating enzymes." In other words, the success rate is less than half that with the general-general version of the question.

Thus, there is strong evidence for Hypothesis 6, that the persistent error is due, at least in part, to problems of recognizing less-familiar, specific instances as well as more familiar, general cases.

Most students avoided the specific answer choice, "tryptophan," in spite of the popularity of the more general class, "amino acids", as an answer. This probably reflects uncertainty as to whether or not "tryptophan" is an amino acid, since it may be confused with tyrosine (another amino acid), thymidine (a nucleoside), or possibly other substances in the cell. On the other hand, students presumably recognize that "activating enzyme" is an enzyme, yet 45% selected "enzymes" as a correct answer while only 25% selected "activating enzymes." This may be explained in part by the next and last hypothesis.

> *Hypothesis 7. There is, in some students' minds, a contradiction between the role of activating enzymes as part of the mechanism of translation and the role of activating enzymes as products of translation.*

Students recognize that activating enzymes (like amino acids, transfer RNA, and messenger RNA) are involved in protein synthesis. How can the substances that are making the product also be the product? (Can a machine tool be used for making a machine tool?) A substance can't make itself, but it may take part in making substances just like itself. Students may be failing to make this distinction, confusing the class of substances (activating enzymes) with the particular members of the class (activating enzymes) present at any given point in time.

To test this hypothesis, 20 students in introductory biology were given the original form of the "translation" question, and 19 received a similar question in which "digestive enzymes" replaced "activating enzymes." This was done because activating enzymes are directly involved in protein synthesis, but digestive enzymes are not. Of the 20 students receiving the first question, one (5%) chose the correct answer (activating enzymes); of the 19 students

receiving the second question, five (26%) chose the correct answer (digestive enzymes).

This data supports Hypothesis 7, that there is a contradiction in some students minds between the roles of activating enzymes as (a) players in and (b) products of protein synthesis.

SUMMARY

In summary, I have described a misconception which is prevalent among and persistent in students of biology and genetics: that amino acids are produced by genetic translation. A seemingly simple multiple choice question on this topic has been consistently answered incorrectly by 75% of the students in introductory biology and 45% of students in an upper division genetics course, over a ten year period.

In accordance with Norman's suggestion (1981) that cognitive errors typically have multiple causes, various possible underlying causes of this cognitive error have been examined. The evidence suggests that the following processes play a major role in the generation of this error:

> 1. Word Association. A strong semantic link between two words ("translation" and "amino acids") which occur with one another, simultaneously and repeatedly, in the context of instruction about protein synthesis appears to be a major factor in error generation.
>
> 2. Instantiation. Another major source of difficulty is that when students learn general principles, they they do not readily recognize specific instances. Stated more generally, when knowledge is acquired at one level of the knowledge hierarchy (the familiar level), students do not readily

> move up the hierarchy to more general classes or down the hierarchy to more specific instances (less familiar levels), even when they know the rules for doing so.
>
> 3. Role Conflict. Some students perceive a role conflict where there is none, finding it difficult to accept that activating enzymes can be both products of and participants in translation.
>
> 4. Knowledge Gap. Students do not have a clear understanding of where amino acids do come from; if they did have a competing mental model, it would presumably be more difficult for them to believe that amino acids are produced by protein synthesis.

Thus, a persistent misconception about the topic of genetic translation has been observed in populations of biology and genetics students over a ten-year period. Several underlying causes of the error have been identified and their relative contributions to the frequency of error occurrence in populations have been examined.

It appears that two underlying causal mechanisms account for about 60% of the error generation. The first is a general, domain-independent characteristic of the cognitive processor, that of word association (operating, in this instance, with two domain-specific terms). The second is the tendency for students to acquire and store information in familiar terms (those specifically used in instruction), without necessarily thinking about implications, more general classes, or more specific instances. Even when students know the logical relationships necessary to move up and down the knowledge hierarchy, they do not readily do so. This presumably involves some generalized cognitive skills, metastrategies, and/or mental habits as well as domain-specific knowledge.

Two additional underlying causal mechanisms involving relevant domain specific knowledge play a lesser but nonetheless important role. These are the lack of knowledge about amino acid biosynthesis and the apparent role conflict of activating enzymes as both players in and products of protein synthesis.

It is not clear how the relative contributions of underlying causal mechanisms to error generation in populations corresponds to sources of error within individuals. For example, if the general/specific (familiar/unfamiliar) dichotomy described in Hypothesis 6 accounts for about one-fourth of the errors made by biology students, does this mean that (a) this problem occurs regularly in one-fourth of the students, or (b) this source of error operates in all students about one-fourth of the time, or (c) something else?

There appears to be no difference in the frequency of the error among (a) students who were exposed to the concept for the first time in this course and (b) students who had previous knowledge of the concept. This suggests that time of exposure may not be an important factor in the creation of a "deep-seated" or persistent misconception.

The methodology used here, using variations of multiple choice questions to probe the characteristics of a particular misconception among groups of students, may be generally useful in misconception research.

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Notes

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TABLE 1

MOST FREQUENT RESPONSE TO THE STIMULUS WORD "PROTEIN"

BY DIFFERENT AGE GROUPS

STIMULUS	MOST FREQUENT RESPONSE WORD				
Group:	College	Hi School	Jr High	Elementary	
Class:	undergrad	11th	9th	6th	5th
N:	23	27	31	22	23
PROTEIN:	AMINO ACIDS	MEAT	MEAT/FOOD	FOOD	VITAMINS

TABLE 2

EFFECT OF LENGTH OF EXPOSURE TO CONCEPT ON FREQUENCY OF ERROR

	% Correct	
HEARD ABOUT PROTEIN SYNTHESIS	ORIGINAL VERSION	OTHER VERSIONS
Only in this Course	28.6	47.9
Elsewhere	23.5	52.2

TABLE 3

WHICH OF THE FOLLOWING IS A PRODUCT OF TRANSLATION?

MODE	ANSWER CHOICES	NUMBER	PER CENT
General/ General	A. amino acids	9	20
	B. proteins	27	59
	C. mRNA's	9	20
	D. tRNA's	1	2
		46	101
Specific/ Specific	A. tryptophan	8	17
	B. activating enz.	22	47
	C. mRNA's	13	28
	D. tRNA's	2	4
	no answer	2	4
		47	100
Specific/ General	A. tryptophan	2	4
	B. enzymes	21	45
	C. mRNA's	12	25
	D. tRNA's	10	21
	no answer	2	4
		47	100
General/ Specific	A. amino acids	21	38
	B. activating enz.	14	25
	C. mRNA's	13	24
	D. tRNA's	4	7
	no answer	3	5
		55	99

INVESTIGATIONS ON CHILDREN'S CONCEPTIONS IN PHYSICS: WHICH METHOD FOR WHICH RESULT?

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The aim of this paper is to bring elements for a reflection on methods of investigation, through an analysis of the nature of the data we got with the methods we tried in our laboratory.

Our investigations can be classified into two main categories:

1. Studies of children's conceptions at a given moment (for example, at the age when we plan to introduce a given field of physics);
2. Studies of the evolution of children's ideas with a teaching.

Our approach is an empirical one, i.e. we don't build our investigations upon an a priori learning model.

We will discuss the tools we used, successively for each of the two kinds of studies defined above. The examples will be taken from researches conducted with 11-14 year olds on light, on physical properties of gases and on heat and temperature.

STUDIES OF CHILDREN'S CONCEPTIONS AT A GIVEN MOMENT

We used, as others, individual interviews and written questionnaires. We could discuss their respective advantages, but a more fundamental question we would like to discuss first is, for both, the nature of the questions we ask to the child.

The open/closed character of the question

1. An example with interviews.

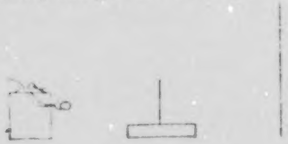
Let us consider the following dialogue, which takes place at the beginning of an interview conducted in order to find out some of the ideas children have about eight (15):

I. Does the candle make light ?
S. Yes
I. What tells you that ?
S. The flame makes light, when you light it
I. Just tell me anything that come into your head. Would you describe how the flame actually makes the light.
S. The wick. The wax helps it to burn.... the wax on the outside of the wick
I. ...What would happen to that light afterwards. Does it do anything ?
S. Not until the candle wears down, unless you blow it out and it wears down
I. What happens to the light through, does it stay around the candle or does it move away from the candle ?
S. Its got light, moves right around. In a dark room, it would light up the whole room.

It might be tempting to conclude from this piece of dialogue that the student has ideas about light travelling. This we cannot do because the idea of the movement of the light is introduced by the interviewer, and not by the student first. To overcome the possible introduction of ideas by the interviewer we have tried a more open type of questioning.

In our interviews, we used two different kinds of questions. In what we call a non directive interview, we ask the child very general questions ("What do you understand by light ?" "What does light do ?" "Where is there light ?"), the rule being to encourage the child to express himself without any more precise question which could induce some kind of answer. Such questions enable us to find out what properties and what range of his own personal experience are spontaneously linked by the child to the word "light", for example. It appeared, so, conceptions on which we could not have designed specific questions, for we could not have suspected them before. In the case of light, for example, it appeared that, for most 10-11 year olds and some 13-14 year olds, light is not that entity located by the physicist between its source and the spots where it produces some effect, but is equated with the source or the effects themselves, no mediator being identified between the two (2) (12). When asked "where is there light ?", such children answer "in the bulbs", or point to the bright spots produced by the sun on a wall; in the whole interview, they never make use of dynamic terms, such as "sets off", "goes through", and so on, in connection to light. The student who said "in a dark room, it would light up the whole room" could have been equating light with its effect, the lighting of the room.

We used, in addition, a second type of interview in which the questions were designed to explore systematically the physical notions we were interested in. Indeed, if a child does not spontaneously evoke a question, that does not mean he has no idea about it. In what we call directive interviews, we set experimental situations in front of the child and we ask him to anticipate or to interpret a phenomenum. For instance, to explore the idea of the rectilinear path of the light, we set up a small bulb (not connected), an upright stick and a screen, and asked the child to explain what a shadow is and to predict the exact size and position of the shadow, by drawing it on the screen. Some thread and rules were on the table, among a lot of useless objects.



The interest we find in such a question is that it gives the child an opportunity of making use of the idea of rectilinear path, but is open enough to let him interpret the situation in his own frame of reference. Some children interpreted the shadow, like the physicist, in terms of an obstacle blocking the passage of light, light being considered then as an entity in space.

> "..The light, uh... sets off. And then it meets an object.... It lights it up, but behind, it can't cross it ...So it's black, then that makes the shadow" (E6, 14 years 10 months).

We could then see wether those children attributed to that entity the property of following straight lines, or not. With other children, light appeared again as equated with the source or the effect. They were then unable to propose any mechanism for the formation of the shadow and could only note the similarity of shape between the object and its shadow.

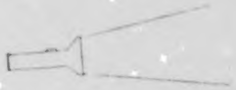
(There's shade) Because there are... tables which **hide the light**. ....(A shadow) It's the **reflection** of a... of a person or a thing.... You can't really see the person.. You just see the shadow. ....the light shines on the person.. behind the person, reflects his shadow" (G1, 14 years 4 months).

"(A shadow) it's a... it's a **reflection** but... it's a **darker light** " (E5, 15 years).

2. An example with questionnaires.

In questionnaires too, a closed question can be misleading. We asked the following question to test the idea of the propagation of light with 14-year-old children who were going to be involved in the experimentation of a project in optics.

That drawing represents the beam of an electric torch:



What can that light be best compared to ?

☐ Running water (like that of a river)
☐ Still water (like that of a canal)
☐ Other suggestion or comment:

☐ I do not know

We analysed 234 answers. The analogy with running water was chosen by 36% of the children, almost the same number as for the choice of the second analogy (41%). We could have concluded that the movement of light in space was fairly popular among the children, if some children had not added a comment to their choice. Here are those comments:

> "I think it can be compared to running water, because when we light the lamp, in the light beam there are small specks of dust which are continuously moving."
>
> "It can't be a canal because that one is straight, a river can widen out."
>
> "To the water of the river, because it widens out as it flows."

Except the last comment which includes an idea of movement, none of the child who chose the analogy with running water did explicit the idea that light moves. Many children answered in relation to the shape of the beam, without paying attention to the opposition between running and still water in the analogies proposed. Among the others suggestions given by the children we found a jet of water from a pipe, a waterfall, but also a road seen in the distance, a building in perspective, a double ladder, a funnel, an ice-cream cornet... When we offer the children a ready-made analogy we never know which aspect of it they will take into account. The same can be said for the tests in which the child is asked to choose between ready-made explanations, unless the reasons of each choice have already been investigated with a more open type of questioning.

The frame of reference of the question

1. Nature of the physical situation involved.

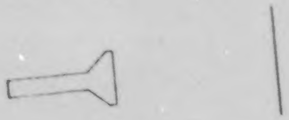
We would like to make here an other point, which appear to be a fundamental one, in relation to the nature of the questions we ask. We found that situations which the physicist explains the same way can provoke quite different answers from the same child. For instance, after a teaching on heat and conduction, when asked to choose a container to keep hot water hot as short a time as possible, Marie-Noëlle (12 years old) chose a metallic one and justified her choice with the idea of the tranfer of heat through the material (6):

> "..it's a conductor and the hot water will go in the sides... no, well, the hot water's heat will go on the sides... well it will go through, and we will feel the hot which will come, which will go in the air."

But to bring hot soup to neighbours on a cold day, she chose an aluminium pan because:

> "..we made experiments showing that temperature was higher and aluminium keeps heat. Because as coffee.. coffee pots keeps in the heat well. The soup will cool down more slowly with the aluminium pan."

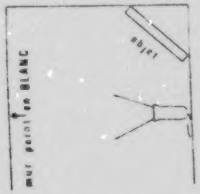
In that situation, she makes no more use of the concept of conduction, but refers to the usual function of metallic coffee pots. It appears then, that we cannot decide with a single answer wether a child has a given concept, or not. We found many instances of the context dependance of children answers. A further step would be to try to determine which characteristics of the situation generated such kind of answer. In the previous example, we can only say that the situations were different in that the second one refered to everyday life. In an other instance, one of the hypothesis we can make about the origin of the different answers relates to the structure of the situations proposed. That instance is the following one, which relates to the reflection of light by objects. In our directive interviews on light with 13-14-year-olds (3) (12), the child was shown a sheet of white paper, and then a mirror, placed opposite an electric torch. We asked him "When I turn on the torch, what does the light do ?"

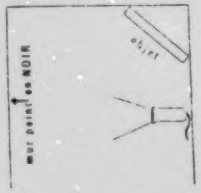


Most of the children said that the light remained on the paper, while the mirror sent it back:

> "(The light) it bounces off the glass (gesture of the child going from the torch to the mirror, then towards herself).... When the light falls on the paper, that makes a screen... It stays there... whereas the glass sends the light back" (E11, 14 years).

Such a conception derives directly from perception: with the mirror you can light up something else or flash a light in someone's eyes, while with the paper, the most apparent effect takes place on the paper the child had in front of him. For children of this age, light means intense light. When it is not intense enough to be perceptible, it doesn't exist any more. To determine the distance up to which a glowing incense stick was sending out light, many children took a small bit of paper and determined the distance up to which they could see a red spot on it (3) (12). In several instances, the assimilation of light with light producing strong perceptible effects seems to be a clue to understand children's interpretations. But when we change the context of the problem set to the child, we can obtain opposite answers based on quite different arguments. In a written questionnaire, we tested the idea of the reflection of light by presenting the two following diagrams which represent a shop-window, first with a white wall, then with a black one.





The children were asked wether the object placed in the shop-window would be lit with the spot-light oriented in that way. As the children interviewed, the children involved had never been taught physics. But they answered quite differently: 30% of them answered, in the case of the white wall, that the object would be lit because the wall reflects light; the same answer was also given by 10% of the children for the black wall. The question was an open one, the children introduced themselves the word "reflects" (or "throws back", "sends back",..). We can then say that the idea of the reflection of the light is present among children of this age for other objects than mirrors, though that idea was exceptional in the interviews. As we have a good correlation between the interviews and the questionnaire on other questions, we do think that the difference in the answers must be related to differences in the situations on which beared the question, rather than to differences in the sample who answered. The main differences between the questionnaire and the interview seems to be, first, that with the written questionnaire the children had no present perception of the spot of light on the wall, maybe also that the situation included a receptor for the light eventually reflected, and finally that the situation of a shop-window was similar to the familiar one of a room, which is known to be lit everywhere with a single lamp.

The conclusion we draw from such results is that a child can "have" some given notion (reflection of light), but not use it systematically. In some instances, he can call upon other ideas (perception, light = intense light,..) which are also stocked "somewhere" in his brain; he can even, then, be led to give answers contrary to the first notion. Investigating children conceptions is not simply determining wether a child has or has not got such conception, but determining if the child happen to call it upon and, also, in what range of situations that conception is prevalent on other types of explanation.

2. Physical situations / general questions.

In the preceeding analysis of the nature of the questions, we compared questions bearing on various physical situations, given to the child. The point we made then applies also to the comparison of general questions, such as the one we used in the non directive interviews ("What do you mean by... light ?", "heat ?", ..), and questions bearing on clearly defined physical situations, such as those of the directive interviews. The knowledge we call upon in both cases can be different, because the frame of reference is different. When a child (aged 14) answers the question "What is heat for you ?" by saying "..for me it is very difficult to bear heat, because it makes us sweat" (16), he does not make a statement relevant to the models of physics. But a physicist can make the same statement when he is speaking in his everyday life. He will use the concepts of physics when he needs them, i.e. when he has to explain a given physical situation. The role of physical concepts is to help us to explain and anticipate the world around us. To know wether a child is able to make use of physical concepts, we must provide him occasions of using them, i.e. problems set on physical situations where they are useful. The general questions of the non directive interviews brought us information, as we showed earlier, but they cannot be used alone. If the work we do is about physics, we cannot avoid physical situations, we could even add "situations clearly analysed in the frame of reference of physics".

By way of conclusion

The preceding sections do clearly not form an exhaustive inventory of what makes a "good" question. We just wanted to raise some points which appeared fundamental to us. We argued for open questions (at least, when a research is at the stage where it has to discover which are the possible conceptions of the children in the field studied), because they let the child express his own frame(s) of reference. But we pointed out that the questions we ask (and the answers we get) must be analysed in relation to the frame of reference of physics, if we are concerned with physics and the learning of physics.

In our laboratory, we investigated children's conceptions on light (2) (3) (5) (12), heat (4) (6) (9), air and pressure (7) (9) (10) (14), electricity (1) (8), particular structure of matter (11).. in relation to the design of curriculums for the age under consideration. Knowing the ideas held by the children at the "moment" when a teaching was planed, allowed us to choose objectives fitting better the needs and the abilities of the pupils, to design and to select experiments which are more likely to help them to acquire the concepts chosen (13). To go further, we need to know in which way children's ideas are, and can be, modified by the teaching.

STUDIES OF THE EVOLUTION OF CHILDREN'S CONCEPTIONS WITH A TEACHING

We will compare, here, three different types of investigations we used to study the interaction of a teaching with children's ideas:

- the first one has been conducted on some children within a standard class;
- the second one is an investigation with a small group of some children;
- the last one is a large scale one, which involved about 600 students in standard classes.

The nature of the data we get is different for each case.

Study conducted on some children within a standard class

That type of study has been conducted about the notion of pressure of a gas, in the case of children 11-13 years old (7). We observed, and recorded on video tapes, all the activities of 3 children working together in a standard class of 24 students, during all the physics and biology lessons bearing on air, over a period of 16 months. We analysed then the transcripts of the tapes and the written tests answered by the children all along the teaching.

In the teaching we observed, the children have been confronted several times with problems dealing with the same notion. We could, thus, follow the evolution of children's ideas during the course of the teaching. The teaching style of the teacher played also an important role in the recollection of our data, as she introduced a lot of experimental activities and encouraged constantly the children to express their ideas, find their own solutions, their own explanations. Endly, the fact that the children chosen were readily speaking ones has also been fundamental.

The children had different initial ideas, and some of them constituted stumbling-blocks for the child. The children evolved also with different rythms. It took Nelly several months to make use of such notion introduced by the teaching. On the other hand, we saw Laurent evolve almost from one experiment to the other. At the beginning of the teaching, Laurent thinks that air exerts forces only if it is compressed. At the third session of the first year, he says thus:

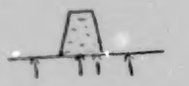
> "No, it (the air of the classroom) doesn't exert any pressure, because it takes the capacity it wants. It is well off. And so it exerts no pressure. We, now, we don't have to exert any pressure. We are quite well. But if we are in a very small box, we will try to push against the box so that we can go away."

But in the forth session, after an experiment where a partial vacuum has been made in an oil-can, he begins to take into account the atmospheric pressure and its actions:

> "We don't feel it, the atmospheric pressure, it's because we have air inside us. If we were empty as the can, inside, we would get quite deformed."

Then he discusses that way with Stephane, about the experiment where a glass full of water is turned upside down:

Laurent: "The paper, it sustains it, the air....
Air, it attacks it."
Stephane: "If air pushes here, normally the paper
should bend on the sides."
Laurent: "Yes but air pushes also on the other side."



The observations we can make this way, in the context of a real standard class, give evidence that the children's conceptions we observe in laboratory situations (i.e. situations specially set up for research purposes, an individual interview for example) occur and play a role in the learning which takes place in schools. For the teachers particularly, the context of a standard class, quite similar to their own ones, makes the results particularly credible and striking.

Study conducted with a small group of some children

In a research on heat and conduction at the age of 12-13 (6), we chose to work in the context of an experimental teaching given to a small group of eight children. With that context, the recollection of data was easier than in a whole class where the research worker has not always the opportunity of making the child explicit his/her idea. We could also have a better mastery of the learning conditions, as we could decide with the teacher the content of the lessons without, for instance, the constraint of a French national program.

The teaching took place once a week, over a period of 3 months. We focussed our investigations on the cases of two girls working together within the small group of eight children. We made video-recordings of all their activities. Those activities were chosen so as to put the children in situations where their interpretations and expectations, when wrong, were contradicted, to allow the children to ask themselves questions about the phenomena under consideration, and to provoke discussions among them. One of us was present, and encouraged the girls to express and try their ideas while working. We made individual interviews with all the children of the group, before and after the teaching. All the children answered also a written questionnaire during the last session, and other written tests all along the teaching. To analyse those data, we took as a point of reference the changes in the points of view the children expressed before and after the teaching. We tried then to see when, and under which observable conditions, that new conceptions of the two girls (Marie-Noëlle and Isabelle) occured in the course of the teaching

Before the teaching, when Marie-Noëlle is asked about phenomena which involve heat transfers, she interpretes them in terms of state (state of the situation, state of the object). Her explanations are based on the current use of the objects, on perceptions.. Thus, when asked to choose a container to keep hot water hot as long a time as possible, she picked a metallic one, because:

> "..doing his national service, my father had little plates like that and he put his coffee in them, and so it kept hot.."

To keep an ice cube frozen, she chose again a metallic container, because:

> "Metal cools things, metal is cold."

At the end of the teaching, Marie-Noëlle has acquired a new idea, the idea of transfer of heat through a material. We already gave an instance of it with a quotation of Marie-Noëlle we made in a preceeding paragraph (page 4). We also saw that she had not lost then her initial reasoning, in which she deduced some property of a material from the familiar use of objects made of that material. The analysis of the teaching sessions allowed us to infer the way the new idea had been integrated in Marie-Noëlle's set of ideas. The modes of learning defined by D.E. RUMELHART and D.A. NORMAN (17) appeared to apply to the evolution of Marie-Noëlle. Up to the 7th session, Marie-Nöelle just accumulated pieces of information drawn from the experiments she made, without reorganizing her thought (accretion mode). At the end of the teaching, a restructuration had taken place (restructuring mode), but that restructuration was a partial one, as Marie-Noëlle happened to use also former kinds of explanations. Isabelle evolved differently, and her case appeared to refer rather to the tuning mode defined by D.E. RUMELHART et D.A. NORMAN.

We could endly relate those different evolutions of the two girls to the conditions of the learning which had taken place. Among the elements which could be responsible for the positive evolution of the first girl and the lack of evolution of the second one, this research pointed out the opportunity given by the teacher and the ability of the child to: put questions to himself about the phenomena under consideration, explicit his/her point of view, and be confronted to contradictory results or points of view.

That research and the preceeding one allowed us to study some mechanisms of evolutions, as they were clinical ones. The last type of investigations we will describe now is a quite different one, as it is a large scale study, whose purpose is to determine what are the effects of a given teaching on a whole population of a given age.

Large scale study

We made a research of that type in the case of the teaching on notions relating to heat and temperature and to physical properties of gases at the age of 11-13 (9) (14).

That research involved 600 ~~pupils~~ students during two years, 11 teachers of the classes under investigation and two research workers. For such numbers we used questionnaires. But we used also some clinical means of investigations:

- individual interviews with some students of each of the classes,
- observations of the way a small group of students solves some problem set about an experimental situation,

and we gathered some written works done by the students during the lessons:

- reports of the students on some experiments.

These additional data helped us to interpret the results of the questionnaires.

Let us examine one example of the way those various tools brought us complementary contributions. With the questionnaires, we observed, for instance, that much less children had acquired the idea of the stability of the temperature in the case of the melting of ice, than in the case of the ebullition of water. With the results of the questionnaires we could not go further. With the analysis of the reports made by the students on observations of the ebullition of water and of the melting of ice, one reason appeared for that difference: the children do not consider water and ice the same way, i.e. a given amount of water can have different temperatures, whereas an ice cube is only "cold", and not "more or less cold".

Such a research lets us define the levels of the concepts which match a given population. It gives rise to the definition of better teaching contents, and so differs basically from the two preceeding ones, and particularly from the second one whose prospect was a better knowledge of what learning is.

FINALLY, WHICH METHOD ?

We said that it was not enough to be able to describe children's conceptions of a given age range (conceptions at a given moment). We need to find out how these conceptions can be modified and, thus, to enter upon studies of evolutions. But studies at a given moment are necessary stages, first because they give tools for the evolution studies, and above all because evolution studies are at most interesting if they are done on a teaching which a priori matches the needs of the students. To define such a teaching, a knowledge of the students initial conceptions is unavoidable.

If we compare now the three pieces of work described above in the field of evolution studies, we see there an example of the strong link existing between the nature of the data we can get, and the method we use. We do believe that various approaches which highlight various aspects are necessary: the complementarity of studies about mechanisms of learning, and studies about the final effect of some teaching on a whole population is an example of that statement; an other example was given when we showed that we need to confront a child with various situations, to really know to which extent he is able to make use of a given concept. But we would like to stress again, as we did in the first part of that paper, that any question does not necessarily bring relevant data. To judge of the value of a result, we must know the way it has been got.

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SELECTED SCIENCE MISCONCEPTIONS AMONGST SOME NIGERIAN SCHOOL CERTIFICATE STUDENTS

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Introduction

For long, psychologists have maintained that the internalization of new information by a learner depends on his existing cognitive structure. Piaget and Inhelder (1969) assert that the learner assimilates new information into his existing cognitive schemata. Ausubel et al. (1978) conceptualize learning of new information as a process of subsumption by preconceptions already possessed by the learner. There is thus a consensus that regardless of age, the learner continually invokes his earlier learnt concepts in order to internalize or interpret for himself the new material.

In other words, the backgrounds and previous experiences of pupils are generally believed to be prerequisites to effective teaching and learning. The identification of misconceptions or common errors in popular notions of scientific concepts and facts is, therefore, one of the considerations in effective science teaching.

The "unsophisticated" ideas that children acquire outside the classroom influence their perception and interpretation of the material read in a text or a teacher's statements. These "naive conceptions" have been termed "alternative frameworks" by Driver and Easley (1978) who indicated that they persist in children's minds despite systematic teaching of competing scientific concepts and constructs. Alternative frameworks, as they pointed out, arise from students' personal experience of natural phenomena and their attempt to make sense of them for themselves before instruction. Further, a misconception is regarded as an idea incorrectly assimilated. In practice, it is difficult to distinguish these and these are not separated for the present purpose. In short, the interpretive frameworks (or alternative frameworks) pupils bring to formal learning situations and the incorrectly assimilated ideas constitute misconceptions or misunderstandings.

Hence, when a pupil employs his naive alternative framework or misconception to interpret classroom information, he is likely to assign it a meaning which is different from or even in conflict with what the teacher originally intended. As Nussbaum and Novick (in press) indicated, it is possible that the learner is ignorant of this disparity and may think that he has correctly interpreted his teacher's information. The teacher frequently attributes the pupils' misrepresentation of facts given in a lesson to a lack of understanding. Nussbaum and Novick have asserted that "this is not a matter of the pupil 'not understanding' but of his understanding differently what was intended."

Again, Garone (1960) has pointed out that science misconceptions could be traced to improper reliance on common sense and to the misinterpretation of one's experiences, while Za'rour (1975) emphasizes that it requires very thorough teaching to make pupils detach themselves totally from erroneous beliefs that appear to be backed by common sense. Doran (1972) states that "a knowledge of common misconceptions related to science phenomena and principles can be of extreme value to the curriculum developers and classroom teachers since it enables them to know where the student is."

Against this setting, this paper aims at briefly reviewing the erroneous notions about some biological and physical science concepts which were very prevalent among Nigerian school certificate candidates (Soyibo, 1981).

Method

Fifty-three specially constructed and validated questions on photosynthesis, respiration and related physical science concepts (labelled "core concepts") were presented orally to 100 school certificate (or GCE 'O' level) candidates in individual interviews to probe their understanding of these concepts. The participants, 50 boys and 50 girls, aged 15 to 19 years, who were prospective candidates for the June 1980 school certificate (SC) biology examination, were selected from a boys', a girls', and a mixed secondary school in Ibadan by a stratified random sampling technique. Their responses were tape-recorded, later transcribed and scored using certain predetermined criteria. The commonest principal misconceptions pupils held on the concepts tested were carefully noted.

Results

Below are listed the 17 widespread misconceptions of the subjects and the percentage response in respect of each misconception.

	Physical Science (or Core) Concepts	% Responses
* 1.	Pressure is force or 'something' exerted in doing anything.	68
* 2.	Energy is the capacity to do anything or 'work' in its everyday sense.	63
* 3.	Osmosis is the movement of a weak sugar solution into a stronger solution.	70
	Photosynthesis	
1.	Root hairs have vascular bundles.	70
2.	Water and mineral salts are conducted via the phloem or via the xylem and phloem.	52
3.	Oxygen always passes into the leaf and carbon dioxide always passes out.	60
4.	Chlorophyll manufactures food during photosynthesis.	90
5.	Starch is the end product of photosynthesis.	98
	Respiration	
* 1.	Only animals use oxygen for respiration.	87
* 2.	A respiratory organ conducts the process of respiration.	84
* 3.	Respiration occurs only in the lungs or gills.	95
* 4.	Organisms respire to get rid of waste products (i.e. excretion).	66
* 5.	Respiration is the taking in of oxygen and giving out of carbon dioxide.	90
6.	Plants respire to produce their food.	51
7.	Plants respire only in the day.	42
8.	Plants respire only in the dark or night.	45
9.	Anaerobic respiration can never occur in humans.	98

Discussion

To ascertain which of the above misconceptions or alternative frameworks was derived solely from pupils' everyday experience outside the classroom or from classroom teaching itself would obviously have required additional interviews. Ideally, these interviews should have been conducted to evaluate pupils' knowledge of the core, photosynthesis and respiration concepts before any formal instruction was given on these aspects at the SC level. Not withstanding, it seems that generally, while those asterisked were more likely to have been picked up outside the classroom, the others are more likely to have resulted from pupils' classroom educational encounters.

For instance, the misconception relating to osmosis is more likely to have originated from the biology class than anywhere else. As copious evidence from the subjects' transcripts showed, many of them did not conceptualize diffusion as the independent and random movement of molecules of substances to areas of lower concentration. Even those who defined osmosis by referring to an area of high or low concentration, lacked an understanding of what exactly is concentrated, i.e. water or sugar molecules, because they usually referred to the concentration of the entire solution.

Furthermore, the term 'pressure' is used in common language to mean 'force.' When a child or even an adult says he applied pressure on something, what he really means is that he applied force. A pupil whose knowledge of pressure is restricted to the concrete level of 'push' is likely to misunderstand other concepts that require, say, an analytic comprehension of pressure. This perhaps explains why it was only some of the few pupils who were able to define 'pressure' that succeeded in applying the analytic knowledge of pressure in some other related questions asked. For example, an analytic knowledge of pressure was required in the question numbered R7 asked on the mechanism of mammalian ventilation (Soyibo, 1981, p. 233).

In sum, the vast majority of the subjects held the misconception that respiration means breathe. Since plants do not outwardly breathe like animals (e.g. humans), it seems that, to most of them, plants do not respire always like animals as a result. Thus, the asterisked misconceptions of the students under respiration concept and the related one (Number 3) under photosynthesis concept, appeared to have blocked their understanding of the very essence of respiration. Most of the subjects, therefore, failed to clearly understand that respiration essentially involves energy release from food substances in all living cells in the presence or absence of molecular oxygen.

It is necessary to examine the fundamental root of the subjects' misconceptions. Barrass' (1979) review, for instance, suggests that pupils (i.e. first language learners of English) have already got the word 'respire' in their vocabulary prior to their formal lesson on respiration. Contrary to the biologist's conception, the term 'respire' to them means 'breathe.' Consequently, their preconception blocks the incorporation of the biologist's meaning into their conceptual structure.

The problem facing the subjects sampled (mostly Yorubas) learning biology in the English language, which is a second language, is, however, quite different. It does appear that the basic source of their misconceptions was either due to the absence in their first language (Yoruba) of a number of words or expressions equivalent to those in the English language, or the absence of certain concepts in their own language (Strevens, 1976, p. 56). Specifically, they do not have the words 'respire' or 'photosynthesis' in their everyday Yoruba vocabulary.

Although a word like 'respiration' and terms like 'respiratory organ' and 'internal respiration' do occur in the English usage of these students, they use their Yoruba equivalents to make them meaningful to themselves. The Yoruba equivalent of the word 'respire' is *breathe* and *ipso facto*, 'respiration' means the breathing in and out of 'air.' It is to be noted that words like 'oxygen' and 'carbon dioxide', associated with respiration, are actually absent in the students' own language. They are simply referred to as air.

Furthermore, the biology teacher often equates the biological term 'respire' with a Yoruba word meaning 'breathe' in an attempt to make students understand the term. The teacher is, therefore, instrumental in implanting this misconception. It is not actually derived from everyday expression of the subjects as is the case with their English counterparts. Hence, 'respiration' to the average Yoruba student means breathing in and out (or gas exchange) within an organism/animal without any reference to energy release.

The biology teacher also implants the misconception that starch only is the end product of photosynthesis, while most of the subjects misconceived the precise function of light and chlorophyll in the process. It is to be noted that, although at the SC level, knowledge that photosynthesis results in carbohydrate synthesis is valid, in reality, lipids or proteins rather than carbohydrates may be formed if the former are lacking in a photosynthesizing organism.

To assist the students to overcome their misconceptions on respiration, it is essential that the teacher should stress that the process involves the release of energy from food substances in all living cells in the presence or absence of oxygen. In short, the teacher should desist from equating respiration with breathing (or gas exchange) which mainly facilitates efficient energy release in most organisms. The concept of 'energy,' as being released in the form of heat during respiration, is present in the subjects' own language. Photosynthesis should be perceived simply as the process by which green plants manufacture food in the presence of light. While simple sugar is the first carbohydrate formed, starch is only the first visible product that can easily be tested to confirm that photosynthesis has occurred.

Summary

The paper may be seen as an attempt to focus teachers' and curriculum developers' attention on some science misconceptions that impede students' explicit understanding of physico-biological concepts and phenomena. The study should motivate teachers to look for and analyze the incorrect answers students give to test questions in view of the useful feedback that could result. It is hoped that some awareness on the part of teachers and educators of common misconceptions in science, may stimulate them to finding possible solutions to this problem.

With specific reference to students, like those sampled, for whom English is a second language, the teacher should avoid implanting basic misconceptions in his students. This can be done by his having an unambiguous understanding of the basic concepts, such as respiration and photosynthesis, being taught. Accurate words or expressions in the students' own language should be used as the equivalents of such concepts in the English language.

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MISCONCEPTIONS OF OSMOSIS

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The understanding of osmosis presents a significant challenge to many students. Expert conceptions of this physical phenomenon often entail subordinate concepts of concentration, semipermeability and pressure. Misconceptions of any or all of these subordinate concepts may result in erroneous solutions to osmotic problems. A detailed study of student responses to a wide variety of osmotic problems has allowed us to characterize a number of misconceptions of concentration, semipermeability and pressure. Comparative studies, conducted on students prior to and following instruction, indicate which of these misconceptions are most stable and thus require particular instructional attention. Some novel demonstrations are suggested as a means for modifying persistent conceptual misunderstandings.

Imagine the following situation. A membrane is placed in a U-shaped tube so as to separate the tube into two halves. At the beginning of an experiment, a dark-colored solution of red dye and water is placed on the left side of the membrane and a light-colored solution of red dye and water is placed on the right side. The membrane allows water to pass freely from one side to the other but prevents dye molecules from passing through it. A diagram of the experiment is presented in figure 1. What will happen to the level of the solution in the left side of the tube? What will happen to the amount of water in this side?

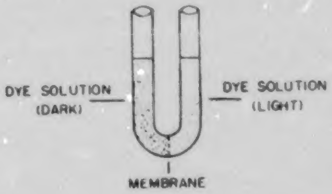

Figure 1. An experiment using a U-tube device.

When a problem like this is presented to a number of students, they answer that the level of the solution will fall because the water decreases in the left side of the tube. A similar number of students are convinced that the level will remain the same because there is no net movement of water. In reality, the level will rise because the net movement of water is into the left side of the tube.

This observation is consistent with osmotic theory which explains that when two liquids are separated by a semipermeable membrane, one molecular species will show net movement across the membrane in a direction determined by the concentration differences of that species and the hydrostatic pressure differences of the two liquids. In the above problem only water is free to move across the membrane. Since water is less concentrated on the left side of the membrane, as visualized by the darker solution, and the hydrostatic pressures are equal on both sides of the membrane, osmotic theory predicts that water will move to the left side of the tube thus elevating the level of the solution. The net movement of water will cease when the pressure (hydrostatic) potential equals the concentration (osmotic) potential.

A key to solving osmotic problems lies in one's conception of concentration. Without recognizing that the intensities (concentrations) of the dye solutions have something to do with the direction of the net movement of water in the U-tube, a solution to this problem is largely a matter of guesswork. How do students' conceptions of concentration compare with those of experts? What misconceptions do students have about concentration?

In a series of studies done by Sandra DeNardis (1983) and myself at the University of Illinois at Chicago, college students were asked to use their conceptions of concentration to select the most concentrated of three chemical solutions, as well as the most dilute of three chemical solutions. The results of a representative study indicate that prior to instruction, over one-third of college students solve concentration and dilution comparisons in a fashion consistent with expert performance. After instruction on osmosis, nearly two-thirds of these students appear to be operating with a clear and stable concept of concentration. The most frequent misconceptions observed are those which involve students who appear to be operating with an undergeneralized concept of concentration. Other types of misconceptions appear to be based on comparisons of amounts of solutes or solvents or solutions. Scientific conceptions of concentration are based on relational comparisons such as the amount of solute in a given amount of solvent or in a given amount of solution.

We believe that the results of this study indicate that conceptions of concentration and dilution may be acquired through everyday experience. Although science instruction may elaborate one's conception of concentration, numerous everyday experiences such as preparing the mornings orange juice and sweetening one's Kool-Aid, coffee or tea provide a sufficient basis for the acquisition of intuitive conceptions of dilution and concentration. These intuitive conceptions can be modified with relative ease to provide a foundation for the scientific conceptions needed to understand the role of concentration in osmotic events.

If you are familiar with the concept of osmosis, or even if you just think about the U-tube problem just presented, it is clear that concepts other than concentration are involved in understanding osmotic situations. In fact, experts often use conceptions of membrane permeability and pressure in finding solutions to osmotic problems. We will begin by considering conceptions of membrane permeability.

Think about the following event. At the beginning of an experiment, a glass funnel was filled with a mixture of dye and water, covered with a membrane, and placed in a beaker of pure water. The results of the experiment are shown in Figure 2. What can you conclude about the movement of dye or water or both through the membrane? Is the membrane permeable (open to passage) to water or dye or both or neither?

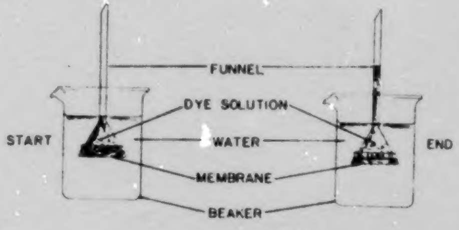

Figure 2. An experiment using an osmometer.

When presented with such a problem, the vast majority of college students answer questions such as these in a consistent and rational fashion. Nearly two-fifths of the students agree with experts that water moves through the membrane, but dye (or some other solute) does not. About a quarter of the students think that both substances move through the membrane. Around one-sixth of them think that the dye (or some other solute) moves through the membrane but water does not. Only a very small percentage thinks that neither moves. The remaining students are more hesitant in their conclusions and give a range of inconsistent answers.

Experts familiar with osmosis, colligative properties of solutions, kinetic theory of gases or thermodynamics are likely to tell you the change in the level of the dye and water solution is indicative of the semipermeable (or selectively permeable) nature of the membrane.

It seems unlikely to us that student conceptions of membrane permeability are acquired through intuitive experience with everyday events. Although science teachers may present analogies of big doorways and little doorways and tall people and short people, or open windows and half-closed windows and beach balls and basketballs, the truth of the matter is that membrane permeability events occur at the microscopic (molecular) level of human experience. Concepts of semipermeability are acquired through instruction in science.

How does instruction influence student conceptions of semipermeability? Standard instruction in college biology usually presents a brief discussion of a semipermeable membrane, a drawing of an example of osmosis and a laboratory demonstration using some type of osmometer. With rare exception, the membranes used, or referred to, are semipermeable; in some cases, these membranes are said to be selectively or differentially permeable. In a number of studies conducted with college students, we found that the proportion of students who used the concept of semipermeable membrane increased significantly after receiving instruction. The results of a representative study are shown in figure 3. Over 80% of instructed students believed that the membrane was semipermeable (i.e. allowed the solvent to pass through, but prevented the solute from doing so). This is in sharp contrast to their beliefs prior to instruction. Only about 40% declared the membrane to be semipermeable. Clearly concepts of semipermeability can be strengthened

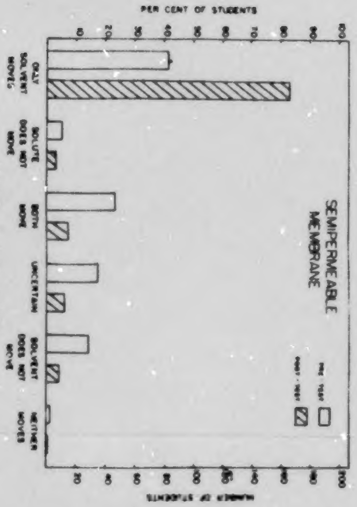

FIGURE 3 · RESPONSES

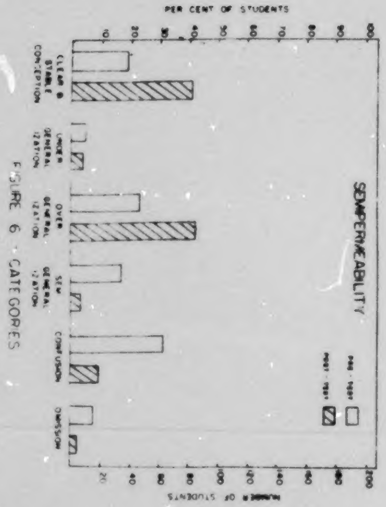

FIGURE 6 · CATEGORIES

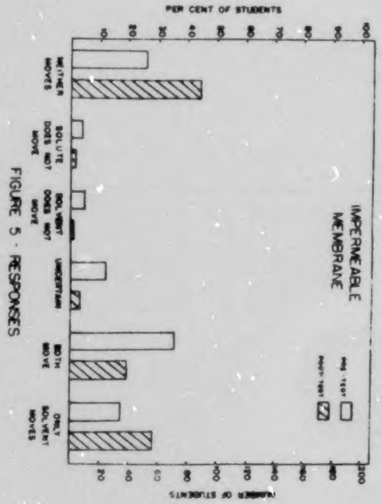

FIGURE 5 · RESPONSES

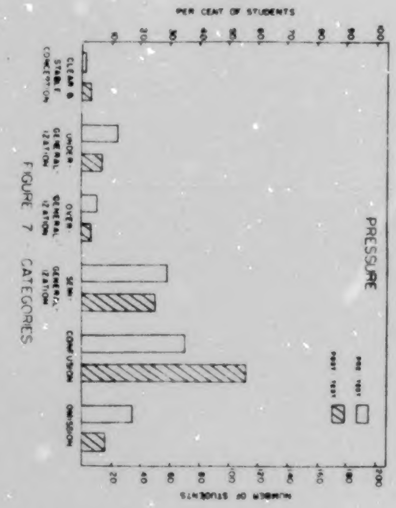

FIGURE 7 · CATEGORIES

through minimal instruction. But do students have a clear and stable concept of semipermeability? Can they recognize instances where a membrane is not semipermeable?

Experts recognize three major classes of membranes: freely permeable, semipermeable and impermeable. How do instructed and uninstructed students perform when presented with situations which resemble osmosis but include impermeable membranes? Figure 4 shows an example of an osmometer-like device equipped with an impermeable membrane.

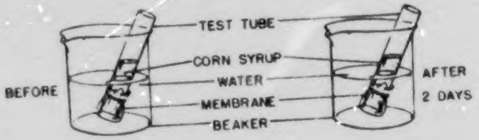

Figure 4. An experiment using an osmometer-like device.
Adapted from an illustration used by Thurber et al, 1975.

Prior to instruction, about one quarter of the students believed that nothing moved through the membrane (see figure 5). A smaller proportion believed that the solvent moved but the solute did not. A very small proportion believed that the solute moved but solvent did not. The largest proportion thought that both solvent and solute moved. The remaining students were less certain in their responses.

After instruction, the proportion of students who believed that nothing moved increased significantly, but equally striking was the fact that the proportion of students who believed that only the solvent moved also increased. Although some students had picked up the idea of impermeability, others saw all osmotic-like systems as having semipermeable membranes. With this observation in mind, we set out to design a set of experiments to see if students could determine when to use the concept of semipermeability and when to refrain from using it.

Students were presented with the results of an experiment using an osmometer and another experiment conducted with an osmometer-like device (see figures 2 and 4). These experiments were varied so that the only difference between them was the class of membranes used in the experimental set-up. Students were asked questions concerning the movement of solute and solvent. Their responses to questions concerning the two experiments were classified on the basis of six conceptual categories. The results of a representative study are shown in figure 6.

Prior to instruction, approximately one-fifth of the students exhibited expert performance; after instruction, those exhibiting this type of performance doubled. Students who recognize when to use a conception of semipermeability and when to refrain from using this concept are said to have a clear and stable concept of semipermeability. A similar proportion of students appear to have an overgeneralized conception of semipermeability; these students believe that the solvent moves but the solute does not, even though the results of the two experiments do not confirm this belief. It is clear that the proportion of students who overgeneralize actually increases after standard instruction. This result, although somewhat disturbing is not surprising (Tiemann and Markle, 1978). Standard instruction on osmosis rarely provides the student an opportunity to distinguish between the results of experiments which use semipermeable and impermeable membranes. Clearly, instruction could be improved by presenting students with experiments which use osmometer-like devices equipped with impermeable membranes.

The results of this study provide evidence on another important category of misconceptions characteristic of students prior to instruction. We call this misconception "confusion." These students frequently distinguish between the results of the two experiments and, in many cases, respond as if they believe both membranes to be semipermeable. However, they often assume that the solute moves through the semipermeable membrane, whereas the solvent moves through the impermeable membrane. This misconception is significantly reduced by standard instruction.

In addition to concentration and semipermeability, pressure often plays an important role in osmotic events. Osmometers are devices designed to detect pressure differences. The differences in heights of liquids in the two containers of an osmometer (i.e. thistle tube and beaker) provide a measure of hydrostatic pressure above and below the membrane. The net movement of water through a semipermeable membrane ceases when the pressure (hydrostatic) potential equals the concentration (osmotic) potential.

How do students' conceptions of pressure influence their understanding of osmosis? Do students detect clues of pressure differences in osmometer or osmometer-like experiments? If so, how do they think that pressure influences the movement of solvent through a semipermeable membrane? To gain some answers to these questions, students were presented with the results of experiments which have been previously described in figures 2 and 4. They were asked questions similar to those which follow.

> The heights (levels) of the liquids in both the beaker and the funnel (or test tube or thistle tube, depending on the specific apparatus used) exert a pressure on the membrane. At the beginning of the experiment, the pressure on the funnel side of the membrane is ___________ (greater than/less than/equal to) the pressure on the beaker side of the membrane. At the end of the experiment, the pressure on the beaker side of the membrane is ___________ (greater than/less than/equal to) the pressure on the funnel side of the membrane. Explain the reason for your choice.

The results of a representative study on students' conceptions of pressure are shown in figure 7. An astonishingly small proportion of students exhibited expert performance on problems related to pressure even after instruction. The majority of students exhibited confusion prior to instruction, and the instruction given actually made matters worse. Although these students often believe that pressure differences exist in some situations, in no case do their beliefs conform to that of experts. In many instances, their beliefs were exactly opposite of those held by experts. For example, over 80% of the students, who were asked to give reasons for choosing their answer, believed that pressures on both sides of the semipermeable membrane were equal at the end of an osmotic experiment. A parsimonious interpretation of the reasons they gave for this choice is that pressure "pushes" water from the beaker through the membrane. As one student stated, "greater pressure on the beaker side caused the water to move to less pressure, therefore equalizing the pressure." Another student said, "the water went into the funnel from the beaker and then stopped so the pressure must have been equal." In all likelihood, student conceptions of pressure arise from everyday experience. In everyday terms, pressure often means "to push." An explanation of pressure as a "push," however, appears to be too simple, since many students refered to concentration differences in the reasons for their answers. For example, one student wrote, "the higher concentration of water moves to the lower concentration of water until it reaches a sort of a balance of concentration, therefore also balancing the pressure on the membrane." Further work will be required to understand students' misconceptions about pressure as it applies to osmosis.

Even some experts seem not to have fully resolved pressure effects on osmosis, at least in terms of molecular explanations. A recent study of pupils' responses to a model of water transport recommends that students be told, "when pressure becomes equal on both sides (of a semipermeable membrane), no net flow takes place" (Johnstone and Mahmound, 1981). At a more fundamental level, Barrow (1979) stated that the similarity of the expression $\Pi = MRT$ to the ideal-gas law "led van't Hoff and others to some not very fruitful ideas that view osmotic pressure as arising from a molecular-bombardment process." In discussing osmotic pressure, Nave and Nave (1980) stated that "the awkwardness of this concept is probably sufficient explanation of its confused use in the literature." Botanists appear to have largely abandoned the use of the term osmotic pressure (McClendon, 1982), and recent biology texts appear to be moving in that direction (Curtis, 1983; Keeton, 1980).

For those with interests in science instruction, it is clear that new ideas and new experiments will be required to prevent the establishment of stable misconceptions of pressure among students learning about osmosis. Any truly fruitful attempts along these lines are likely to arise from further research on the nature and origin of conceptual misunderstandings of concentration, membrane permeability and pressure.

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Misconception About Evolution Among Secondary School Pupils in Kuwait

MOH'D SAID SUBBARINI (1)

ABSTRACT

Collection of opinions was involved in deriving a needs-assessment of Kuwaiti Society for biological education in secondary schools. Pupils in secondary schools as well as other groups in Kuwaiti society were consulted. Teaching evolution was met, by the different groups, with various degrees of cold welcome, caution, or frank opposition. Antagonism of evolution is based on presumption or misunderstanding or misconception that evolution goes against religious beliefs. However, as evolution is a central concept in the science of biology it is argued by biologists that it should be included in school biology. Moreover it is shown that evolution is compatible with religious beliefs.

PROCEDURE AND FINDINGS

In developing school biology programmes in Kuwait, there was previously no assessment of what was acceptable to various groups of people, in terms of their needs and opinions (Subbarini, 1983 p. 417a). Educational programmes, however, must not be imposed on the community, but, otherwise they should be developed in tune with its requirements (Soto, 1977 - p.248).

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(1) Dr. M.S. Subbarini is the Senior Science Supervisor in the Ministry of Education - Kuwait. The research which forms the basis of this paper was carried out by Dr. Subbarini while a research student at the University of Southampton - England.

Regarding opinions, different groups of Kuwaiti Society (pupils, school teachers, university students, university teachers, futurists, and parents) (1) were consulted. The sources of opinion consulted are ultimately the beneficiaries of secondary school biology. Whilst pupils are the direct customers of school biology, the other groups are the dominant influences on the flow of information related to pupils' opinions.

Data collection from such a variety of groups necessitated the use of varied tools in order to supplement one with another to counteract the particular bias of each tool. The tools used were, interviews, group discussions, and an opinionnaire.

In "interviews" a small representative sample (n=15) of the different groups of Kuwaiti Society were interviewed with the aim to explore, in a deep face-to-face discussion, perceptions, interests, and preferences in biological education. All necessary procedures to secure validity and realiability, and to avoid interviewer bias, were taken in conducting, recording, transcribing, and analysing data (Galfo and Miller, 1970. p. 37, 38; Skager and Weinberg, 1971, p.118; Weirsma, 1969, p. 275; Mason and Bramble, 1978, p.300; Turney and Robb, 1971,p.134-135; Englehart, 1972, p. 109, 114, 115; Rummel, 1964, p. 100, 104; Morton-Williams, 1978, p.15, 20, 25; Best, 1970, p. 187; Oppenheim, 1966, p.36; Wood, 1978, p. 100; Gay, 1976, p. 135; Verma and Beard, 1981, p. 114).

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(1) Terms used in this paper are defined at the end (Appendix-A).

In "group discussions" four groups were included in four different sessions: members in non-governmental Societies (1) (n=5), biology teachers in Bedouin areas (n=8), Heads of Biology Departments in secondary schools (n=12), and Senior Masters and Senior Mistresses in secondary schools (n=49). The intention in holding the group discussions was to collect as much data as possible in a short time, and to get the benefits of the stimulation of new ideas (Weiss, 1975, p. 361) and brainstorming that usually occur in group discussions (Pratt, 1980, p. 87). Appropriate teachniques and precautions were undertaken in each group discussion to ensure validity and reliability of the data collected (Weiss, 1975, p. 361, and Van Dalen and Meyer, 1966, p. 307).

As a wide spread opinion on bioligical education was sought, and inferences about attitudes and opinions was to be explored, an opinionnaire was chosen as the most convenient tool for that purpose (Mason and Bramble, 1978, p. 300). In sample selection the whole target population was chosen in some cases, i.e. University Teachers (TU), Heads of Departments and Senior Masters and Mistresses (TS). In other cases a random representative sample was chosen, Pupils (PL), Students (S), Futurists (F), and Parents (PR). Necessary techniques were employed for obtaining a random sample to avoid exercising direct control on sample selection, and thus prevent bias in the results (Van Dalen and Meyer, 1966, p.298). All necessary procedures of objectivity were taken in construction, readability, validity and reliability of the opinionnaire (Oppenheim, 1966, p.26, 36, 43; Van Dalen and Meyer, 1966, p. 302; Turney and Robb, 1971, p. 130, 131; Best, 1970, p. 162; Mason and Bramble, 1978, p. 301; Courtenay, 1978, p. 51).

Items included in the opinionnaire were, largely, based on:

(i) background review of biological education in Kuwait.

(ii) review of regional and international developments in biological education.

(iii) data collected from interviews and group discussions.

Regarding the statistical analysis of the data, laborious statistical computations were not required as the interest was more in the descriptive analysis of the data. The aim was to explore opinions on the kind of biology that should be taught in secondary schools.

However, simple analysis, such as frequencies, percentages, means, and standard deviations were computed by a desk calculator. Correlational analysis was not conducted.

In the analysis of the data it was revealed that religious beliefs and views were prominent in influencing the choices of social groups. Helping pupils to develop "appreciation of the greatness of the Creator, through better knowledge of His marvels in the realms of life" was considered as the most important objective of biology teaching. High priority was, also, given to assimilating the contribution of biology to religious education. This is evidenced by the fairly low priority given to the study of "evolution", "sex-selection", and "human races".

"Evolution", in particular, was considered as the least important topic in biology teaching.

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(1) Societies sponsored partly by the **Ministry of Social Affairs** and Labour, and partly by theirmembers. Their activities are mostly oriented to help citizens promote awareness of different social issues.

DISCUSSION

"Evolution" has always been a subject of great controversy. Apart from the differences of opinion among evolutionary scientists (which seems to be particularly very active at present), a major part of this controversy arises from an apparent contradiction between evolution and the belief that nature is the result of God's design, intention, and direct intervention. Evolutionists suggest that living things are undergoing continuous change and that their higher forms have descended from lower forms by a gradual process of modification through natural mechanisms. Creationists, on the other hand, believe that all species of life were created de novo by God and that these forms have not changed substantially since their creation.

Opposition to Darwin and Wallace's announcement of their theory was almost immediate; from scientists, such as Lord Kelvin and Fleeming Jenkin, as well as from clergymen. The famous debate between Thomas Henry Huxley ("Darwin's Bulldog") and Bishop Samuel Wilberforce in 1860, gives a vivid scene of the hot controversy on the subject at that time. Naturally a scientific subject of such a profound impact on religion, philosophy and society, had to create some serious educational problems. Many opponents in the United States condemned the intro[illegible]ion of evolutionary theory into the high school curriculum. In Tennessee for example, an antievolution bill (the Butler Act) became law in 1925. Accordingly, John Thomas Scopes, a County High School teacher, was tried for teaching evolution and found guilty. Forty two years after that Scopes' or "monkey" trial, the Tennessee State Senate amended the Butler Act in 1967 to the effect that "teachers could refer to evolution but only as a theory and must maintain that God's creation is a fact consistent with the Good Book" (Stansfield, 1977, p. 5). The California State Board of Education unanimously approved a set of guidelines directing that the creation theory should be taught as an alternative to the theory of evolution in science classes. The California Supreme Court decided against this policy in 1972, but ordered that textbooks should refrain from "scientific bias in fostering the notion that evolution is the only possible explanation" (Stansfield, 1977, p.6).

It is not surprising, therefore, that teaching evolution has met with various degrees of cold welcome, caution or frank opposition by some people in Kuwait where religion has the upper hand over the people's beliefs and ways of thinking. However, the following analysis seems necessary for a better understanding of the situation:

1. Islam pays great respect for science and scientists. The Koran invites men to study nature and to seek rational knowledge, to find proof of their faith and to live a prosperous life on earth. Thus, when the great Muslim Philosopher Ibn-Rushd (Averros) wrote that "the Koran invites men to observe nature and to seek rational knowledge" (Arnaldez and Massignion, 1967, p.386), he expressed the opinion of all Muslim scholars that the earth was given to man for constant and reverent study. For muslims, seeking knowledge is a personal sacred duty; Prophet Mohammad (peace be upon him) taught people that: "To seek knowledge is a duty of every muslim, male and female", and: "Seek knowledge even though you may have to go to China!". Some scholars interpret the following two verses of the Koran as an open and clear invitation to scientists to study evolution: "See they not how Allah (God) produceth creation, then reproduceth it? Lo! for Allah that is easy. Say (O Mohammad) : Travel in the land and see how He originated creation, then Allah bringeth forth the later growth. Lo! Allah is Able to do all things" (29, 19, 20) (1).

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(1) These and all other Koranic verses in this paper are quoted from: Picktal, Mohammad Marmaduke (1953)- "The Meanings of the Glorious Koran-An Explanatory Translation". George Allen and Unwin Ltd., London.

2. A fair and thorough understanding of Islam would lead to the conclusion that there is nothing is the Koran or sayings of the Prophet of Islam that contradicts the basic scientific principles, or confers Holy orders on Muslims to believe in anything lacking a sound scientific basis or, otherwise, has been proved scientifically to be wrong (Bucaille, 1978, p. 3).

3. With this tolerant and open-minded attitude Muslim Medieval scholars discussed the basic principle of organic evolution. They formed a continuous stream of thought from the ninth to the fifteenth centuries, and many names may be cited, but two examples are of particular interest (Mohammad, 1981, p. 217).

(a) Ikhwan al-Safa' (Brethern of Pruity), who established their group in the second half of the tenth century, wrote a fairly comprehensive encyclopaedia of knowledge in their times. The whole work is classified into 53 epistles (now printed in four volumes, of about 2000 pages), one of which is on "Species of Plants", and another on "Species of Animals". Again and again the Ikhwan point to the natural gradation of beings and their interrelation and unity, but the following quotations indicate something which is more significant:

> "Minerals came first, then plants, then animals, then man" - a clear indication of succession in order and in time".
>
> "Then know, oh Brother, that plants are precedent in being and existence to animals by time, because plants are the material for all animals, primordial matter for their forms, and nutrient for their bodies - as if plants were the mother for animals".

(b) The great Ibn-Khaldun of the fourteenth century, who wrote his monumental history in seven volumes, which made him the greatest Arab historian. But still much greater is the first part of this work, "The Muqaddimah" or "Introduction on Prolegomena", in which Ibn Khaldun proved himself as a philosopher, the father (or one of the fathers) of the philosophy and science of history, and the founder of sociology. In his Introduction, Ibn-Khaldun gave a comprehensive description of the state of the various sciences in the Muslim world at that time. Relevant to our topic, the following quotation is very significant:

> One should then look at the world of creation. It started out from the minerals and progressed, in an ingenious, gradual manner, to plants and animals. The last stage of minerals is connected with the first stage of plants, such as herbs and seedless plants. The last stage of plants, such as palms and vines, is connected with the first stage of animals, such as snails and shellfish which have only the power of touch. The word "connection" with regard to these created things means that the last stage of each group is fully prepared to become the first stage of the next group.
>
> The animal world then widens, its species become numerous, and, in a gradual process of creation, it finally leads to man, who is able to think and to reflect. The higher stage of man is reached from the world of monkeys, in which both sagacity and perception are found, but which has not reached the stage of actual reflection and thinking. At this point we come to the first stage of man after (the world of monkeys). This is as far as our (physical) observation extends (Rosenthal, 1967, p. 195).

In this short passage such statements as "fully prepared to become", "its species become numerous", "in a gradual process of creation". "The higher stages of man is reached from the world of the monkeys". .....are very significant.

If we recall the Wilberforce-Huxley debate, we shall find Sarton was quite justifiable to state that "Christian thrologians were less hospitable to evolutionary views than their Muslim forerunners,...." (Sarton, 1943, p. xix). Indeed, those broad-minded scholars were much more tolerant to scientific and philosophical ideas than many of their grand-children in the twentieth century. Nevertheless most textbooks on evolution ignore the fact. Eaton discussed the causes of the "virtual absence of evolutionary ideas prior to the eighteenth century" (Eaton, 1970, p.3). Stansfield stated that after free discussions of philosophers and theologiansin in the early part of the Christian era, "inquiry and original thinking along these lines virtually ceased" (Stansfield, 1977, p.27) during the intellectual stagnation of the Middle Ages.

4. As a matter of fact organic evolution has been included in Secondary School Biology curricula in Arab countries for many years. In Kuwait it was introduced in 1968 (Al-Karmi, 1968, pp. 513-560). Moreover, the inclusion of evolution as a teaching topic in secondary school biology was, quite recently, promoted through the Alecso Biology Project (1). Sheik M. Sha'rawi the well known Muslim Clergyman in the Arab region gave his full support to including evolution in the Alecso Project. He stressed that the fear from teaching evolution in the notion of its contradiction to Islamic beliefs, is a false one (Sheikh Sha'rawi, 1977, p. 253).

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(1) The Pilot Project for Biology Teaching in Secondary Schools in the Arab states. The Alecso Project is unique at the regional level.

Alecso is the Arab League Education, Cultural and Scientific Organization (Arab Unesco). It was established in 1970 as a specialised agency in the Arab League. Headquarters were originally in Cairo, but in 1979 it was moved to Tunisia.

It is true that objections and criticisms may be uttered occasionally, but this may be taken as an example of extreme tolerance if compared to the Scopes trial in 1925, firing another science teacher again in Tennessee in 1967 for the same reason, or the dismissal of three Roman Catholic nuns in 1969 from their posts in a Staten Island parochial school for teaching "evolution *vs*. creation" (Stansfield, 1977, p.6).

5. Antagonism of our pupils to evolution may arise from two reasons: prejudice and an appropriate approach to the teaching of its principles. Better understanding alleviates prejudice. Teaching evolution *should not* hurt the pupil's beliefs, and, as a matter of fact, it has not to do so. Evolution may be taught as an inherent characteristic of life; God created an evolving world or "Evolution Is God's Method of Creation" (Denank, 1973, p. 216). The idea that living things have an innate mechanism initiating and directing their evolution is not strange to science. H. Graham Canon, for example, concluded that all the evidence he presented in his book leads "inexorably in one direction: to the conception of some guiding force within the organism which controls and guides its evolution, not by haphazard changes but by selected modification" (Canon, 1958, p. 141). Again Peacocke writes: "The ideas of God creating through an evolutionary process is now fully accepted by Christians but its implications have not yet been fully realized and worked out" (Peacocke, 1971, p. 123).

It seems that such was the idea of the Ikhwan, Ibn-Khaldun, and other Medieval Muslim scholars who presented evolutionary thought. It is true that these broad-minded scholars did not present a "mechanism" of evolution (except for this innate urge and potentiality of living beings to progress), but all the essential elements for an evolutionary concept were clear in their minds. In addition to reasonably good biological information, they had an excellent understanding of geological phenomena and a remarkable feeling of "geological age". Moreover, the various travellers' books and encyclopaedias of natural history provided knowledge of the wide variety of vegetable and animal life essential for initiating evolutionary speculations. It may be concluded that these early pioneers believed in some sort of "evolutive creation" (Mohammad, 1981, p. 217).

CONCLUSION

Teaching evolution in secondary school biology did not gain wholehearted support from the different groups in Kuwaiti Society. Nevertheless the importance of evolution to a general biological education Programme requires that it should be included and it requires particular attention during implementation.

The traditional approach to the teaching of evolution through an investigation of changes which have occured through time e.g. study of fossil record, would not be suitable in Kuwaiti secondary schools, because there is a strong belief among those in the social groups studied, that these ideas are contrary to religious beliefs. However, as evolution is a central concept in the science of biology it is argued by biologists that it should be included. Moreover it can be shown to be compatible with religious beliefs. This apparent conflict can be resolved if one takes into account religious opinion and ideas which support the notion of evolution.

Examples of these are:

(i) the invitations to observe and seek rational knowledge which exists in the Koran and Hadith (sayings and deeds of Prophet Mohammad-peace be upon him-).

(ii) the contribution of medieval muslim scholars who discussed the basic principles of organic evolution.

(iii) the rationale for including evolution in secondary school biology which is discussed in the Alecso Biology Project.

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APPENDIX - A - (Definition of Terms):

Definitions, here are confined to major terms used in the study.

Secondary School: A school that encompasses grade 9 - 12 (age 14-18) of the general education system in Kuwait.

Fourth Secondary Class Pupils: Pupils in grade 12 (age 17 - 18) who were in the last year of their schooling and experienced the whole biology programme in the secondary school.

Students: The 1st year Kuwait University students in the Faculty of Medicine or in the Department of Zoology or Botany, and who attended at least one biology course in the university.

Senior Masters and Mistresses: Those male and female teachers who besides teaching biology in secondary schools, hold responsibility for biology teaching in their schools. Their performance is evaluated by both headmasters and biology inspectors. Teachers after ten years of experience, could be promoted to Senior Masters/Senior Mistresses if they show success in their performance.

Heads of Departments: Those male and female teachers who besides teaching biology in secondary schools, take the role of inspectors in their schools. Their un-official title is, the local inspectors. Their performance is evaluated by headmasters and the Senior Science Supervisor. Usually, outstanding Senior Masters/Mistresses are promoted to Heads of Departments.

University Teachers: Staff members in both the Zoology and Botany Departments at Kuwait University.

Parents: Fathers and mothers who had children in the fourth secondary class (grade 12).

Futurists: Members in the Working Futurusts' Group for Expectations of Kuwait in the Twenty First Century. Futurists worked for two years (1976-1978) under the auspices of the Kuwaiti Society for the Promotion of Family Affairs and projected a picture for Kuwait in the year 2000.

Students' Misconceptions about Photosynthesis:

A Cross-Age Study

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Dr. Martin Luther College

> "Concept development is central to the entire process of education" Smith (1966).

Introduction

The fabric of life is woven out of thin air by light. Indeed, the concept of photosynthesis is one of the most important science concepts a student can learn. We owe our green and habitable world to it. It's not surprising that Arnon (1982) says photosynthesis "eminently merits its distinction as the most important biochemical process on earth."

Just two hundred years ago the process was unknown to scientists. Today's school children have the opportunity to benefit from years of scientific detective work as they study photosynthesis in their science lessons.

But what effect does teaching have on the development of this concept over time? Are there identifiable misconceptions that interfere with learning how plants make food?

Although Martin (1979) developed an instrument to determine botanically related misconceptions, he did not focus on photosynthesis. Test and Heward (1980) divided the photosynthesis concept into four major parts and taught it to juvenile delinquents. They did not, however, concentrate on detecting misconceptions.

Significant research by Roth, Smith, and Anderson (no date) and Lavender and Anderson (1982) at Michigan State University has uncovered a number of misconceptions about photosynthesis in fifth graders and in college students. They also found that virtually no students they studied understood the scientific concept of photosynthesis.

Having done clinical interviews on the child's concept of "away" (the conservation principle) while working under Professor Verne N. Rockcastle at Cornell University (Wandersee, in press), I became interested in studying students' conceptions of the conservation of matter in photosynthesis while working under Professor Joseph D. Novak.

Since my intent was to test a large sample over a wide range of ages, I replaced the clinical interview with a paper-and-pencil instrument designed to probe students' understanding of photosynthesis and to detect prevalent misconceptions. The following is an account of the instrument's development and the results obtained through its use.

Instrument Design

The need to develop a diagnostic instrument capable of detecting the misconceptions that students hold about how plants make food ultimately led to the construction of the Photosynthesis Concept Test (PCT). (See Appendix A for a copy of the test.)

The test consists of 12 tasks, each involving an experiment, a phenomenon, or a situation that calls for a student response. Subjects are asked to make forced choices, free responses, or to complete drawings in order to simulate what occurs in a clinical interview.

As a biology professor, I identified a number of subconcepts that I considered necessary to understanding the major concept of photosynthesis. Subsequently, I generated 12 test tasks that I considered appropriate for the population to be tested.

A jury of three educators, including two college botanists and a high school English teacher, evaluated my items and then made suggestions for change or improvement. The evaluation criteria of clarity, brevity, vocabulary level, scope, and content validity were employed. An indication of the test's construct validity stems from the author's previous work with clinical interviews and Ausubelian psychology.

Preliminary testing of 71 college sophomores using the PCT allowed me to develop a categorical coding key for the answers. Nussbaum and Sharoni-Dagan (1983) have observed that "Although theoretically the number of variations of the alternatives may be as high as the number of individuals, in fact these alternatives tend to fall into a few distinct categories." Thus, free response items can be coded.

The calculated repeat reliability coefficient for the key was .79 and for the test itself, .72. According to Burns (1980), test-retest reliability is appropriate for use when the items that comprise a test are intentionally heterogeneous. He also recommends that test-retest coefficients be in the .75 to .85 range for a test to be considered highly reliable.

Assumptions and Expectations

Assumptions

This study is based on Ausubel's (1968) assimilation theory of cognitive learning and its subsequent elaboration by Novak (1977). Principal assumptions are that concepts are regularities among facts that are designated by a symbol or sign, that meaningful concept learning will occur only when the learner consciously tries to relate new knowledge in a substantive way to concepts which already exist in the learner's cognitive structure, and that meaningful concept learning is the goal of science education.

It is also assumed that learners tend to use the most proximate and relevant concepts available in order to assimilate new concepts into their conceptual structure. Therefore it appears critical that learners acquire a base of appropriate and factual subsuming concepts before they are exposed to higher-level learning tasks. Thus misconceptions may be defined as concepts improperly linked to or subsumed by existing concepts in the learner's cognitive structure. Misconceptions can also be erroneous new concepts.

Expectations

The problem was to detect common misconceptions students harbor about the concept of photosynthesis and to investigate whether their conceptions change as they are exposed to additional information about photosynthesis in progressively higher grades.

It was hypothesized that there would be no significant differences between the frequencies of students from a particular grade falling into each of the possible response categories for a given PCT item.

It was also hypothesized that there would be no significant differences between the frequencies of students falling into a particular response category for a given PCT item across the four grade levels being investigated.

The chi-square nonparametric statistical test was chosen because the level of measurement of the data was nominal (categorical) and the null hypothesis specified a comparison of observed and expected frequencies in discrete categories (Hill & Kerber, 1967). The level of significance was chosen as: alpha = .01. The sample size of 1405 was considered to be random by cluster, representative, and adequate.

Procedure

The administration of the PCT was carried out during the winter months of the 1982-83 school year. Students from 49 schools and colleges in nine states wrote the PCT under the supervision of their regular classroom instructors who followed written instructions for test administration. No time limit was set for its completion--all pupils completed the test within one class period. Pupils in the sample came from both rural and urban middle-class backgrounds.

The sample (n = 1405) consisted of pupils in elementary school (grade 5; n = 420), junior high school (grade 8; n = 393), senior high school (grade 11; n = 383), and college (sophomores; n = 209). (Appendix B shows the distribution of students by state within the sample.)

Answers supplied by the students were numerically coded into response categories by the author. The data was analyzed using a 64K Apple II microcomputer and Econometric and Linear Forecasting System software (TWG, 1982).

Results and Discussion

PCT was constructed to probe students' conceptions regarding selected aspects of the photosynthesis concept. The aspects under consideration in this study were:

(a) the basic function of soil in plant growth and photosynthesis;

(b) the basic role of photosynthesis in the carbon cycle;

(c) the basic roles of the leaf and light energy in photosynthesis; and

(d) the primary source of food in green plants.

The Basic Function of Soil in Plant Growth and Photosynthesis (Tasks 1, 2)

Biologists who examine Task 1 will recognize it as a variation of van Helmont's willow tree experiment. This question was designed to probe the role students ascribe to soil in the process of photosynthesis.

There is a general increase over grade levels in the percentage of pupils favoring the accepted answer ("the soil's weight stayed about the same"). It appears that a majority of fifth and eighth graders expected a large change in soil weight (see Figure 1). Fifth grade students seem more likely to choose a gain in weight. In contrast, the succeeding grade levels' dominant misconception was that the soil would lose a lot of weight.

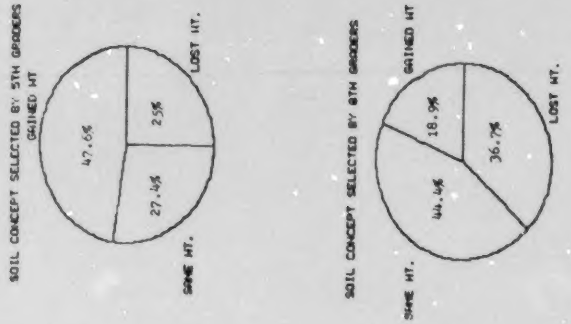
In interpreting any multiple-choice diagnostic test item, a researcher must consider the possibility that the student was guessing. Table 1 presents the results of a chi-square goodness-of-fit type statistical test for each grade level. The observed frequencies of students in each response category within each grade were found to be significantly different from those expected due to chance (guessing) at the .01 probability level.

Table 2 shows the results of a chi-square test of independence in which it was determined that there are significant differences between the four class levels at the $\alpha = .01$ level.

However, if a student answers a particular question incorrectly, the researcher may still not know how s/he arrived at that incorrect answer. Task 2 sought a free response from each student, giving opportunity for explanation of how the decision was made. Table 3 offers a representative sample of explanatory written responses from students at each grade level. The examples were chosen to demonstrate the variety of misconceptions students hold about the role of soil in plant growth and photosynthesis. The explanations were taken (verbatim) from the students' PCT forms.

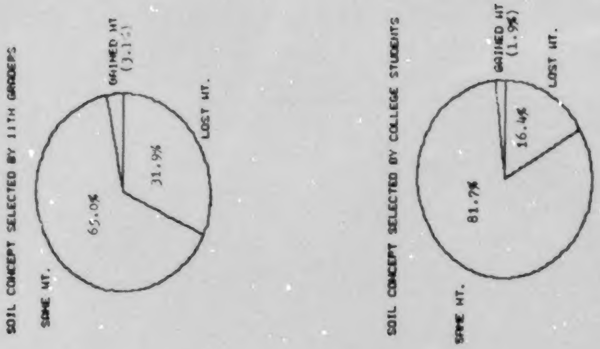
Figure 1

Proportion of Students Selecting Each Option for Task 1


SOIL CONCEPT SELECTED BY 5TH GRADERS

SOIL CONCEPT SELECTED BY 8TH GRADERS

Figure 1--Continued


SOIL CONCEPT SELECTED BY 11TH GRADERS

SOIL CONCEPT SELECTED BY COLLEGE STUDENTS

Table 1

Chi-Square Analysis of Response Differences within Grades for Task 1

Grade	Response			Total
	Lost Wt.	Same Wt.	Gained Wt.	
5	$f_o=104$ $f_e=138.7$	$f_o=114$ $f_e=138.7$	$f_o=198$ $f_e=138.7$	416
$\chi^2 \approx 38.$[illegible] is greater than $\chi^2=9.21$ (2df) at .01 level.				
8	$f_o=142$ $f_e=129$	$f_o=172$ $f_e=129$	$f_o=73$ $f_e=129$	387
$\chi^2 \approx 40.6$ is greater than $\chi^2=9.21$ (2df) at .01 level.				
11	$f_o=122$ $f_e=127.3$	$f_o=248$ $f_e=127.3$	$f_o=12$ $f_e=127.3$	382
$\chi^2 \approx 219.1$ is greater than $\chi^2=9.21$ (2df) at .01 level.				
14	$f_o=34$ $f_e=69$	$f_o=169$ $f_e=69$	$f_o=4$ $f_e=69$	207
$\chi^2 \approx 223.9$ is greater than $\chi^2=9.21$ (2df) at .01 level.				

Table 2

Chi-Square Analysis of Response Differences between Grades for Task 1

Grade	Response			Total
	Lost Wt.	Same Wt.	Gained Wt.	
5	$f_o=104$ $f_e=120.1$	$f_o=114$ $f_e=210.1$	$f_o=198$ $f_e=85.8$	416
8	$f_o=142$ $f_e=111.8$	$f_o=172$ $f_e=195.4$	$f_o=73$ $f_e=79.8$	387
11	$f_o=122$ $f_e=110.3$	$f_o=248$ $f_e=192.9$	$f_o=12$ $f_e=78.8$	382
14	$f_o=34$ $f_e=59.8$	$f_o=169$ $f_e=104.5$	$f_o=4$ $f_e=42.7$	207
Total	402	703	287	n=1392

$\chi^2 \approx 364.0$ is greater than $\chi^2=16.81$ (6df) at .01 level.

Table 3

Representative Sample of Explanatory Written Responses (Task 2) from Students at Each Grade Level

Grade	Task No. 1 Response	Name--Task No. 2 Explanation
5	The soil lost a lot of weight.	Scott--Because the soil is the plants food and without it a plant couldn't live.
		Melanie--cause when you watered it the soil would sink.
		Steve--Because when the plant grew it had to have more room so it had to lose it.
	The soil gained a lot of weight.	Tony--I picked that answer because it sounds right and the soil did gain a lot of weight.
		Brad--becuose it is the way a plant grows.
8	The soil lost a lot of weight.	Vance--Because the plant ate minerals (food) from the soil. That's why the plant got Big.
		Kevin--The carbon and neutrons and oygen went in the plant so it could grow.
		David--The root absored the soil.
	The soil's weight stayed about the same.	Brian--because dirt don't evaparate so it still would be there so it is the same weight.
		Johanna--Because the plant didn't eat the soil. It drank the water.
		Donn--I picked it because the soil had nothing to do with the plant. The water made the plant grow so that tho roots expanded.
11	The soil lost a lot of weight.	Derek--Because when you put water in the pot the water goes out from the hole under the pot some of the soil goes with it.
		Chad--in order to gain 34 lbs. weight has to come from somewhere--sunlight--oxy. do not provide much or any, thus the soil gave up its weight by photosynthesis.
	The soil's weight stayed about the same.	Kevin--The soil is moist from the water and the plant feeds on the water.
11	The soil's weight stayed about the same.	Cindy--When the plant was watered it got proteins from the soil which is needed for it to grow.
		William--Plants get most of the nutrients which they need for growth from water and sunlight. Although my first thought was that these came from the soil, I know this is incorrect.
		Loren--The soil would weigh about the same, maybe a little less, because of the minerals the plant took out of the soil. The soil has very little if any part in the growth of the plant. Plants can also be grown without soil by a certain process (hydrophonics).
14	The soil lost a lot of weight.	John--The plant sucked out all the proteins and minerals of the soil. This loss was not replaced.
		Jackie--Because when the plant grew it was taking all its food out of the soil. The roots are also growing and taking up much more room.
	The soil's weight stayed about the same.	Terry--The energy (thus pounds) is given to the plant by the sun--the sun's rays are weighless. Photosynthesis transfers the rays into energy which is what those extra pounds really were.

Evaluation of student Task 2 responses, after they had been divided into a limited number of discrete categories, showed that some students in each grade level perceived soil to be the plant's food, with increasing percentage (13% to 21%) in higher grade levels. Students' perceptions of the relative importance of water for plant growth decreased (18% to 4%) with increasing grade levels. Pupils used the term "minerals" to explain their answers with greater frequency as grade level increased (6% to 31%). (Some students said plants get "vitamins" from the soil, confusing this word with the term "minerals.")

It should also be noted that a fairly large number of students (31%-45%) gave a written response lacking a statement of causality.

The Basic Role of Photosynthesis in the Carbon Cycle (Tasks 3, 4, 5)

Biologists who examine Task 3 will recognize it as a variation of Priestley's study of the gases released by living plants and animals. This test question was designed to study the perceptions students have of the relationship between photosynthesis and animal respiration in the carbon cycle. The item is intentionally constructed to pose a general problem and allow the student to define the limiting factors that determined his/her answer in the free response task that follows it.

There is a general increase over grade levels in the percentage (38% to 67%) of students selecting the accepted answer ("Both the mouse and the plant would live"). This is accompanied by a decrease in the percentage of pupils who believed that "both the mouse and the plant would die" as grade level rose (34% to 16%). A sizable minority (24% to 10%) thought that only the plant would survive. Figure 2 shows the pattern of responses for each grade level.

Table 4 shows that the observed frequencies of students loading into each response category within each grade were significantly different from those to be expected due to chance (guessing) at the .01 level. Table 5 documents that there also were significant differences between the four grade levels at the $\alpha = .01$ level.

The Task 4 free responses help to explain the students' selection process for Task 3. There was a decreasing emphasis in the use of the term "air" (26% to 4%) as grade level rose. This was also noted for the use of the terms "water" or "food" to explain what happened (26% to 12%). As grade level increased, an increasing percentage of students (18% to 58%) used "carbon dioxide" and "oxygen" to justify their decisions. It should be added, however, that some misconceptions may still be there, embedded in language that often successfully

Table 4

Chi-Square Analysis of Response Differences within Grades for Task 3

Grade	Response: Mouse Lives	Plant Lives	Both Live	Both Die	Total
5	f_o= 20 f_e=105	f_o=100 f_e=105	f_o=158 f_e=105	f_o=142 f_e=105	420
$\chi^2 \approx$ 108.8 is greater than χ^2=11.34 (3df) at .01 level.					
8	f_o= 15 f_e=98	f_o= 49 f_e=98	f_o=213 f_e=98	f_o=115 f_e=98	392
$\chi^2 \approx$ 232.7 is greater than χ^2=11.34 (3df) at .01 level.					
11	f_o= 13 f_e=95.75	f_o= 39 f_e=95.75	f_o=216 f_e=95.75	f_o=115 f_e=95.75	383
$\chi^2 \approx$ 260.0 is greater than χ^2=11.34 (3df) at .01 level.					
14	f_o= 3 f_e= 51.75	f_o= 32 f_e= 51.75	f_o=139 f_e= 51.75	f_o= 33 f_e= 51.75	207
$\chi^2 \approx$ [illegible].4 is greater than χ^2 11.34 (3df) at .01 level.					

Table 5

Chi-Square Analysis of Response Differences between Grades for Task 3

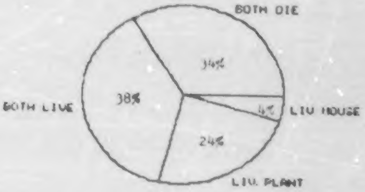
Grade	Response: Mouse Lives	Plant Lives	Both Live	Both Die	Total
5	f_o= 20 f_e= 15.3	f_o=100 f_e= 65.9	f_o=158 f_e=217.5	f_o=142 f_e=121.3	420
8	f_o= 15 f_e= 14.3	f_o= 49 f_e= 61.5	f_o=213 f_e=203.0	f_o=115 f_e=113.2	392
11	f_o= 13 f_e= 3.6	f_o= 39 f_e=60.1	f_o=216 f_e=198.3	f_o=115 f_e=110.6	383
14	f_o= 3 f_e= 7.5	f_o= 32 f_e= 32.5	f_o=139 f_e=107.2	f_o= 33 f_e= 59.8	207
Total	51	220	726	405	n=1402

$\chi^2 \approx$ 99.85 is greater than χ^2=21.67 (9df) at .01 level.

Figure 2

Proportion of Students Selecting Each Option for Task 3

REQUIREMENTS-FOR-LIFE CONCEPT OF 5TH GRADERS



REQUIREMENTS-FOR LIFE CONCEPT OF 8TH GRADERS

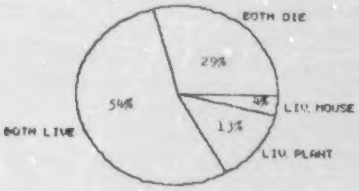
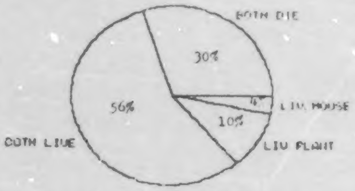


Figure 2--Continued.

REQUIREMENTS-FOR-LIFE CONCEPT OF 11TH GRADERS



REQUIREMENTS-FOR-LIFE CONCEPT OF COLLEGIANS

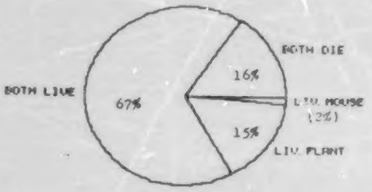


Table 6 Representative Sample of Explanatory Written Responses (Task 4) from Students at Each Grade Level

Grade	Task No. 3 Response	Name--Task No. 4 Explanation
[illegible]	The plant would die but the mouse would live.	Dennis--The plant whood die of sunlight.
		Holly--After a while the plant would die of thirst but at first they will both live because plants need carbon dioxcide and mice need oxegen. If plants have carbon diocide it will give off oxegen and vice a versa.
	The mouse would die but the plant would live.	Casey--I think so because mice don't live under water, and the plant has sunlight on number 8.
	Both the mouse and plant would live.	Brent--Well see if there is a plant the mouse will because what the mouse breath's is the plant's food. And what the plant gives off the mouse can live on.
	Both the mouse and plant would die.	David--Well you did not say you would refill his container of food or water the plant.
		Peter--A mouse needs food and a plant need water, and carbon dioxide not just sunlight to live.
		Dave--They would both drown.
8	The plant would die but the mouse would live.	Christina--The plant might die because it would get to much sunlight. But the mouse might live because their used to being kept in cadges.
	The mouse would die but the plant would live.	Jennifer--The mouse would die, because if the plant just had sunlight and no water it would die, the mouse would live, because he would feed on the fallin leaves.
8	Both the mouse and plant would live.	Tim--(for a while.) Both the mouse and plant would die (eventualy).
		Kevin--I did because the plant gives off carben dioxide and the mouse gives off oxygen.
		Marc--A plant needs hydrogen constantly. In a glass container the plant would die. A mouse needs air and in glass container there is some but not much.
		Mark--It's like carbon dioxide-oxygen cycle, the plant would use the CO_2 to make food and give off oxygen the mouse could use.
		Vicki--The mouse gives off the kind of air the plant needs and the plant gives off the kind of air the mouse needs.
	Both the mouse and plant would die.	Jody--Because if the plant would grow the mouse would reach it and eat it. But if the plant is poisonous the mouse would die. And if the mouse ate the plant, it would die.
		Rachel--Because during the day the plant gives off oxygen but at night the plant gives off carbon dioxide and takes away the oxygen and neither the plant or mouse have oxygen so they both will die out.
11	The plant would die but the mouse would live.	Mike--The plant would die soon after because if the mouse got really hungry it would find a way to get to the plant and proablly eat it and jump from the stool to the outside if it didn't also die in the process.
11	Both the mouse and plant would live.	Kristen--The carbon dioxide--oxygen cycle would be complete. The correct gases for both would be provided.
		Dan--The mouse gives off something so the plant can grow and the plants gives off something for the mouse to live.
		Cheryl--Because they would exchange carbon monoxide and oxygen.
	Both the mouse and plant would die.	Craig--The plant would not be able to produce enough oxygen to supply the mouse's quick metabalism. The mouse would die and the plant would die somewhat later.
[illegible]	Both the mouse and plant would live.	Debbie--for awhile. I feel they would live because the mouse gives off the carbon dioxide the plant needs and the plant gives off oxygen for the mouse. They could live for awhile--BUT NEED WATER.

mimics adult language (Nussbaum and Novak, 1976).

In Table 6, a selection of student responses illustrates both the diversity of extant misconceptions and the depth of some students' conceptual development. It must also be noted that students may make assumptions teachers would seldom anticipate (see those of Casey, Dave, and Jody). The concepts of gases do not seem too well-anchored in some students' conceptual hierarchies; they may confuse the names because they have not learned many meaningful chemical concepts, only rote ones. In addition, a number of students would also rank food and water ahead of oxygen as more important to an animal's survival. To fully appreciate photosynthesis, a person must understand why the oxygen produced by green plants is so important for living organisms.

Task 5 asked the students which gas might decrease in amount after the mouse had been living in the closed glass container (sans plant). The item was constructed to see whether students could identify the gas needed for respiration and serves to aid interpretation of the depth of understanding students might demonstrate in Tasks 3 and 4. The response options included the major gaseous components of air.

Figure 3 shows the percentages of students who chose each option in the four grade levels tested. A large number of students in grade 5 (66%) selected the accepted answer and the percentage rose to 75% for college students. Water vapor

Table 7

Chi-Square Analysis of Response Differences within Grades for Task 5

Grade	Response: H_2O vapor	O_2	CO_2	N_2	Total
5	f_o=53 f_e=99.5	f_o=264 f_e= 99.5	f_o=58 f_e=99.5	f_o=23 f_e=99.5	398
$\chi^2 \approx 369.8$ is greater than χ^2=11.34 (3df) at .01 level.					
8	f_o=51 f_o=97.25	f_o=282 f_e=97.25	f_o=35 f_e=97.25	f_o=21 f_e=97.25	389
$\chi^2 \approx 472.6$ is greater than χ^2=11.34 (3df) at .01 level.					
11	f_o=46 f_e=95.25	f_o=287 f_e=95.25	f_o=21 f_e=95.25	f_o=27 f_e=95.25	381
$\chi^2 \approx 518.3$ is greater than χ^2=11.34 (3df) at .01 level.					
14	f_o=28 f_e=51.75	f_o=156 f_e=51.75	f_o= 8 f_e=51.75	f_o=15 f_e=51.75	207
$\chi^2 \approx 284.9$ is greater than χ^2-11.34 (3df)•at .01 level.					

Table 8

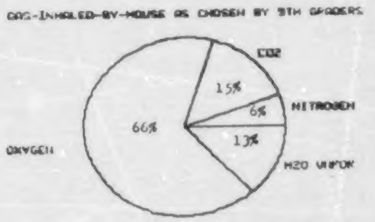
Chi-Square Analysis of Response Differences between Grades for Task 5

Grade	Response: H_2O vapor	O_2	CO_2	N_2	Total
5	f_o= 53 f_e= 51.5	f_o=264 f_e=286.3	f_o= 58 f_e= 35.3	f_o= 23 f_e= 24.9	398
8	f_o= 51 f_e= 50.4	f_o=282 f_e=279.8	f_o= 35 f_e= 34.5	f_o= 21 f_e= 24.3	389
11	f_o= 46 f_e= 49.3	f_o=287 f_e=274.0	f_o= 21 f_e= 33.8	f_o= 27 f_e= 23.8	381
14	f_o= 28 f_e= 26.8	f_o=156 f_e=148.9	f_o= 8 f_e= 18.4	f_o= 15 f_e= 12.9	207
Total	178	989	122	86	n=1375

$\chi^2 \approx 29.74$ is greater than χ^2=21.67 (9df) at .01 level.

Figure 3

Proportion of Students Selecting Each Option for Task 5


GAS-INHALED-BY-MOUSE AS CHOSEN BY 5TH GRADERS

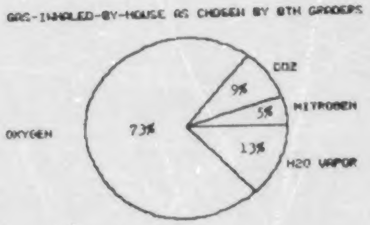
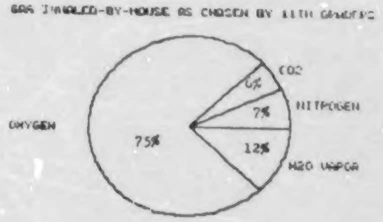
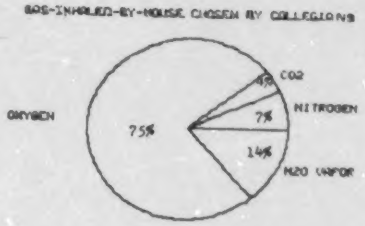

GAS-INHALED-BY-MOUSE AS CHOSEN BY 8TH GRADERS

Figure 3--Continued


GAS INHALED-BY-MOUSE AS CHOSEN BY 11TH GRADERS


GAS-INHALED-BY-MOUSE CHOSEN BY COLLEGIANS

was the second most attractive option for 12% to 14% of students at each grade level. Beyond grade 8, students do not seem as likely to confuse "carbon dioxide" with "oxygen" in explaining respiration.

Tables 7 and 8 demonstrate that there were significant differences both within and between grade levels. The former implies that guessing was not an important source of measurement error while the latter indicates that conceptual change occurred as students progressed to higher grade levels.

The Basic Roles of the Leaf and Light Energy in Photosynthesis (Tasks 6, 7, 10, 12)

Historians of science who examine Task 6 will see a number of ideas the ancients propounded to explain what the leaf does along with the accepted answer ("Leaves make food that keeps the plant alive"). This item is considered critical in assessing students' understanding of the photosynthesis concept.

Figure 4 presents the pattern of student responses to Task 6 by grade level. It is noteworthy that nearly one-half (45%) of the fifth graders tested did not believe that the main job of a leaf is to make food. Almost one-third (32%) of the eighth grade students were also unaware of that. Consider the college students; approximately one-fifth still held contrary notions.

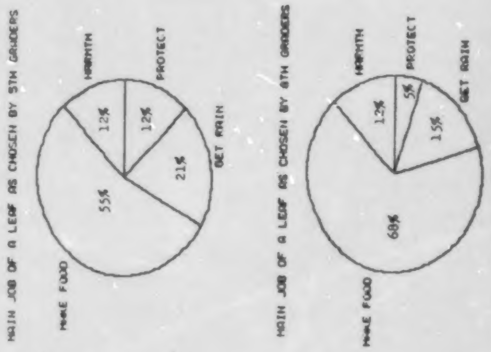


Figure 4

Proportion of Students Selecting Each Option for Task 6

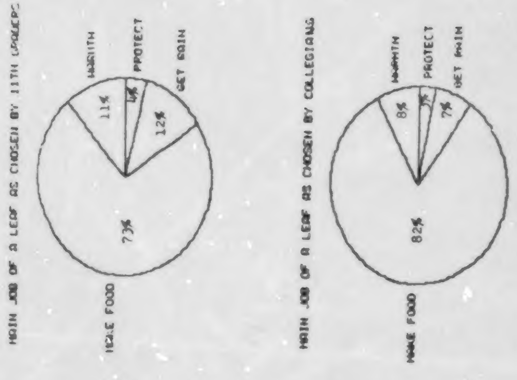


Figure 4--Continued

Tables 9 and 10 reveal significant differences both within and between grade levels for Task 6.

Task 7 asked students to indicate the basic flow pattern of the gases involved in photosynthesis. In requesting that students identify the primary direction that each gas moves, it was hoped that secondary misconceptions about the role of the leaf might be detected.

There were three subtasks (7A, 7B, 7C) for Task 7. Subtask 7A sought to learn whether the student believed the primary flow of carbon dioxide gas was into or out of the leaf during photosynthesis. Figure 5 presents information showing that a large proportion (62%) of the students tested chose the accepted answer (CO_2 moves into the leaf) already at the fifth grade level and the percentage increased to 85% for college students.

There were significant differences both within and between grade levels according to chi-square statistical tests. (See Tables 11 and 12 for documentation of this.)

Subtask 7B asked the student to decide whether the primary flow of water vapor during photosynthesis was into or out of the leaf. Figure 6 supports the analysis that this is a misconception affecting a large proportion of the students tested in all grade levels. The accepted answer (water vapor moves out of the leaf) was not chosen by 62%to 68% of the

Table 9

Chi-Square Analysis of Response Differences within Grades for Task 6

Grade	Response Protect shoots	 Catch rain	 Make food	 Capture warmth	Total
5	$f_o=48$ $f_e=97.5$	$f_o=81$ $f_e=97.5$	$f_o=214$ $f_e=97.5$	$f_o=47$ $f_e=97.5$	390
	$\chi^2 \approx 193.3$ is greater than $\chi^2=11.34$ (3df) at .01 level.				
8	$f_o=20$ $f_e=98$	$f_o=60$ $f_e=98$	$f_o=264$ $f_e=98$	$f_o=48$ $f_e=98$	392
	$\chi^2 \approx 333.5$ is greater than $\chi^2=11.34$ (3df) at .01 level.				
11	$f_o=15$ $f_e=95.25$	$f_o=45$ $f_e=95.25$	$f_o=277$ $f_e=95.25$	$f_o=44$ $f_e=95.25$	381
	$\chi^2 \approx 468.5$ is greater than $\chi^2=11.34$ (3df) at .01 level.				
14	$f_o=6$ $f_e=51.75$	$f_o=14$ $f_e=51.75$	$f_o=170$ $f_e=51.75$	$f_o=17$ $f_e=51.75$	207
	$\chi^2 \approx 361.5$ is greater than $\chi^2=11.34$ (3df) at .01 level.				

Table 10

Chi-Square Analysis of Response Differences between Grades for Task 6

Grade	Response Protect shoots	 Catch rain	 Make food	 Capture warmth	Total
5	$f_o=48$ $f_e=25.3$	$f_o=81$ $f_e=56.9$	$f_o=214$ $f_e=263.3$	$f_o=47$ $f_e=44.4$	390
8	$f_o=20$ $f_e=25.5$	$f_o=60$ $f_e=57.2$	$f_o=264$ $f_e=264.7$	$f_o=48$ $f_e=44.6$	392
11	$f_o=15$ $f_e=24.8$	$f_o=45$ $f_e=55.6$	$f_o=277$ $f_e=257.2$	$f_o=44$ $f_e=43.4$	381
14	$f_o=6$ $f_e=13.4$	$f_o=14$ $f_e=30.2$	$f_o=170$ $f_e=139.8$	$f_o=17$ $f_e=23.6$	207
Total	89	200	925	156	n=1370

$\chi^2 \approx 70.12$ is greater than $\chi^2=21.67$ (9df) at .01 level.

Figure 5

Proportion of Students Selecting Each Option for Task 7A

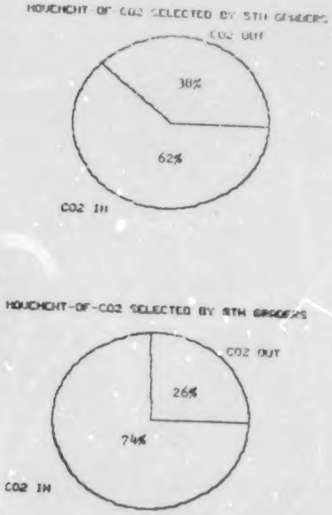


Figure 5--Continued

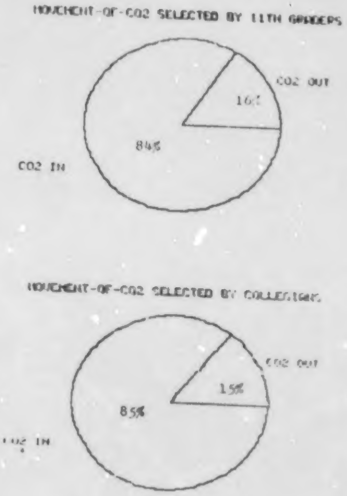


Table 11

Chi-Square Analysis of Response Differences within Grades for Task 7A

Grade	Response		Total
	CO_2 In	CO_2 out	
5	f_o=223 f_e=181	f_o=139 f_e=181	362
$\chi^2 \approx 19.04$ is greater than χ^2=6.64 (1 df) at .01 level.			
8	f_o=271 f_e=182.5	f_o= 94 f_e=182.5	365
$\chi^2 \approx 84.86$ is greater than χ^2=6.64 (1 df) at .01 level.			
11	f_o=304 f_e=182	f_o= 60 f_e=182	364
$\chi^2 \approx 152.22$ is greater than χ^2=6.64 (1 df) at .01 level.			
14	f_o=170 f_e=100	f_o= 30 f_e=100	200
$\chi^2 \approx 96.6$ is greater than χ^2=6.64 (1 df) at .01 level.			

Note. Chi-square was corrected for continuity (for problems with 1 df).

Table 12

Chi-Square Analysis of Response Differences between Grades for Task 7A

Grade	Response		Total
	CO_2 In	CO_2 out	
5	f_o=223 f_e=271.4	f_o=139 f_e= 90.6	362
8	f_o=271 f_e=273.7	f_o= 94 f_e= 91.3	365
11	f_o=304 f_e=272.9	f_o= 60 f_e= 91.1	364
14	f_o=170 f_e=150.0	f_o= 30 f_e= 50.0	200
Total	968	323	n=1291

$\chi^2 \approx 59.43$ is greater than χ^2=11.34 (3df) at .01 level.

Table 13

Chi-Square Analysis of Response Differences within Grades for Task 7B

Grade	Response H_2O vapor in	 H_2O vapor out	Total
5	f_o=223 f_e=181	f_o=139 f_e=181	362
χ^2≈19.04 is greater than χ^2=6.64 (1 df) at .01 level.			
8	f_o=243 f_e=182.5	f_o=122 f_e=182.5	365
χ^2≈39.46 is greater than χ^2=6.64 (1 df) at .01 level.			
11	f_o=249 f_e=182	f_o=115 f_e=182	364
χ^2≈48.60 is greater than χ^2=6.64 (1 df) at .01 level.			
14	f_o=135 f_e=100	f_o=65 f_e=100	200
χ^2≈23.80 is greater than χ^2=6.64 (1 df) at .01 level.			

Note. Chi-square was corrected for continuity (for problems with 1 df).

Table 14

Chi-Square Analysis of Response Differences between Grades for Task 7B

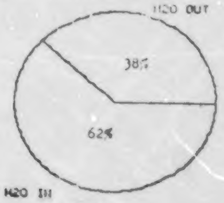
Grade	Response H_2O vapor in	 H_2O vapor out	Total
5	f_o=223 f_e=238.3	f_o=139 f_e=123.7	362
8	f_o=243 f_e=240.3	f_o=122 f_e=124.7	365
11	f_o=249 f_e=239.7	f_o=115 f_e=124.3	364
14	f_o=135 f_e=131.7	f_o= 65 f_e= 68.3	200
Total	850	441	n=1291

χ^2≈4.26 is less than χ^2=11.34 (3df) at .01 level.

Figure 6

Proportion of Students Selecting Each Option for Task 7B

MOVEMENT-OF-H2O-VAPOR CHOSEN BY 5TH GRADERS



MOVEMENT-OF-H2O-VAPOR CHOSEN BY 8TH GRADERS

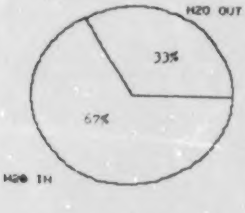
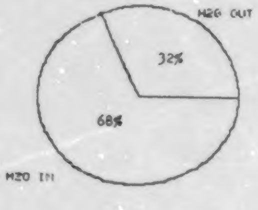
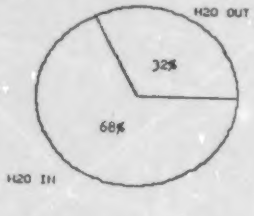


Figure 6--Continued

MOVEMENT-OF-H2O VAPOR CHOSEN BY 11TH GRADERS



MOVEMENT-OF-H2O-VAPOR CHOSEN BY COLLEGIANS



students. In fact, fifth graders selected the correct answer slightly more often than students in higher grade levels; college students were most likely to select the incorrect answer. That is why Table 14 reveals no significant differences between grade levels on responses to this subtask even though Table 13 shows significant differences within each grade level.

Subtask 7C requested that pupils indicate whether the primary flow of oxygen during photosynthesis was into or out of the leaf. Figure 7 displays the results in graphic form. Fifth graders had a difficult time with this question and only 51% chose the accepted answer (oxygen moves out of the leaf). That percentage explains why the (Table 15) chi-square test result for differences within the fifth grade sample was not significant.

As responses across grade levels are studied, it will be obvious that an increasingly greater percentage (75% to 87%) of pupils above grade five answered the question correctly. Table 16 clarifies this observation, since the differences between grade levels were found to be significant.

Task 10 required students to sketch the appearance of two plants, one placed in a dark closet and the other on a window sill. The drawings were categorized by the author. Most students across all grade levels (85%) drew the closet

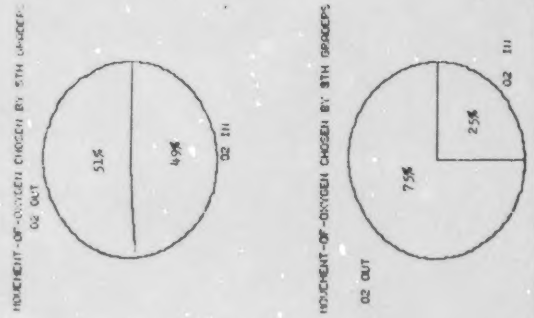


Figure 7

Proportion of Students Selecting Each Option for Task 7C

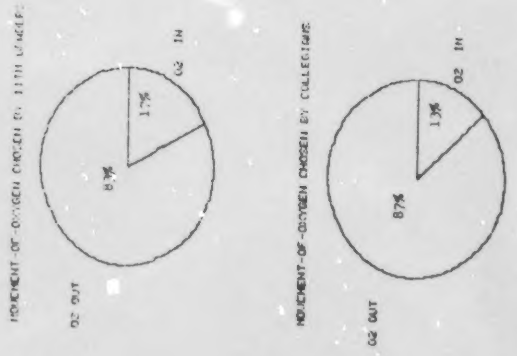


Figure 7--Continued

plant as stunted in growth and unhealthy in appearance. Another 11% drew it as tall, sickly-looking, and etiolated. In contrast, the plant in the window was drawn to look large and healthy by the vast majority (98%) of students across all grade levels. Some students even showed that they understood something about phototropism by showing the plant's stem bending toward the light.

Figure 8 is included to supply examples of the drawings students made in response to Task 10. It appears that most students realize that light energy is a vital part of the photosynthetic process.

The last item on the test, Task 12, was intended to probe the student's awareness and understanding of the pigment chlorophyll and its role in photosynthesis. Students were asked to tell how the color change of deciduous tree leaves in fall (loss of green appearance) affects the leaf's main job. It was anticipated that students might respond that a leaf can no longer absorb sunlight for photosynthesis because its chlorophyll (in its chloroplasts) is no longer intact and functional.

In evaluating the responses, only 24% of the students across all classes mentioned chlorophyll by name. Nearly 24% mentioned the autumn leaf's inability to absorb light. About 56% said that the leaf could no longer perform photosynthesis. A smaller percentage thought that the leaf could no longer

Table 15

Chi-Square Analysis of Response Differences within Grades for Task 7C

Grade	Response		Total
	O_2 in	O_2 out	
5	f_o=194 f_e=199	f_o=204 f_e=199	398

$\chi^2 \approx .29$ is less than χ^2=6.64 (1 df) at .01 level.

Grade	O_2 in	O_2 out	Total
8	f_o=98 f_e=194.5	f_o=291 f_e=194.5	389

$\chi^2 \approx 94.8$ is greater than χ^2=6.64 (1 df) at .01 level.

Grade	O_2 in	O_2 out	Total
11	f_o=66 f_e=190.5	f_o=315 f_e=190.5	381

$\chi^2 \approx 80.7$ is greater than χ^2=6.64 (1df) at .01 level.

Grade	O_2 in	O_2 out	Total
14	f_o=28 f_e=103.5	f_o=179 f_e=103.5	207

$\chi^2 \approx 108.7$ is greater than χ^2=6.64 (1 df) at .01 level.

Note. Chi-square was corrected for continuity (for problems with 1 df).

Table 16

Chi-Square Analysis of Response Differences between Grades for Task 7C

Grade	Response		Total
	O_2 in	O_2 out	
5	f_o=194 f_e=111.7	f_o=204 f_e=286.3	398
8	f_o= 98 f_e=109.2	f_o=291 f_e=279.8	389
11	f_o= 66 f_e=107.0	f_o=315 f_e=274.0	381
14	f_o= 28 f_e= 58.1	f_o=179 f_e=148.9	207
Total	386	989	n=1375

$\chi^2 \approx 129.42$ is greater than χ^2=11.34 (3df) at .01 level.

Table 17

Representative Sample of Explanatory Written Responses (Task 12) from Students at Each Grade Level

Grade	Name--Task No. 12 Explanation
5	Mary--The leaf can no longer take the air palutoin and the noise because of all the people and anamils.
	Stephanie--The leaf can no longer live because it need to be on the tree because it gets its food from the trunk of the tree that gets water from the ground.
	Jodi--The leaf can no longer have green because the green is like blood for the leaf. And the cold almost takes it out.
	Rory--The leaf can no longer get the food that it needs to stay alive on because the green chemical is no longer in the air.
	Rebecca--The leaf can no longer live because the tree is dieing so the leaves fall off.
	Heather--The leaf can no longer get alot of oxygen because most people aren't outside that often.
	Mike--The leaf can no longer breathe so it just changes colors because when people hold their breathe they change colors.
8	Maria--The leaf can no longer make food because the tree is sleeping or resting in the winter.
	Laura--The leaf can no longer gather its water vapor for the tree to survive because its pockets or little gaps it has to gather the water dry up.
	Theresa--The leaf can no longer make food or produce carbon dioxide because they die and turn crunchy.
	Mike--The leaf can no longer live because the cold has frozen the photosynthesis.
	Tanya--The leaf can no longer produce the food and bring in oxygen because the green in the leaf is like the living part.
11	Heidi--The leaf can no longer produce O_2 efficiently because the chemical--chlori eptic (or something like that)--which turns the leaf green and is needed for photosynthesis is no longer present.
	Bob--The leaf can no longer produce chlorine because don't know why they stop.
11	Sally--The leaf can no longer have photosynthesis because the chlorophorm in the leaf is gone.
	David--The leaf can no longer have their beautifull colors because a valve is shut to block out the (green stuff) going into a leaf.
14	John--The leaf can no longer produce food because the nerve endings have lost their sensitivity.
	Patricia--The leaf can no longer pick up the dew and draw in the sunlight for the plant because the leaf has died when it changes color and soon it will fall off the tree.
	Carmen--The leaf can no longer make food for itself because the chemical that makes the leaves green (can't remember the name) is gone, and this chemical is what the plant uses in photosynthesis.

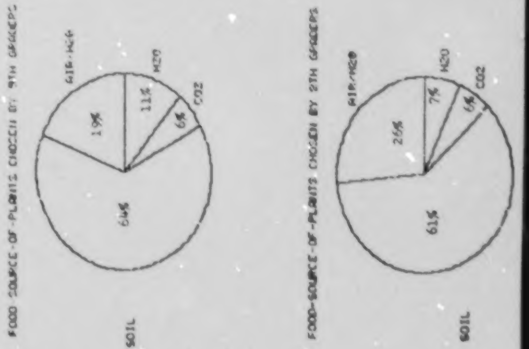


Figure 9

Proportion of Students Selecting Each Option for Task 8

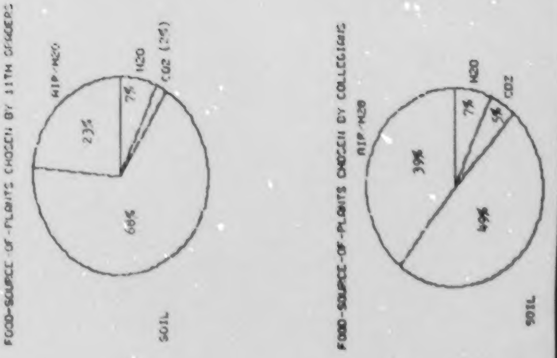


Figure 9--Continued

dioxide for food making. This contradicts Weier, Stocking, Barbour, and Rost (1982) who point out that ". . . only about 1% or less of the water absorbed by the roots is actually used in photosynthesis."

Students who chose the option "The food of plants comes from water and air" may even know that the CO_2 in the air is a reactant in photosynthesis but still may believe that water is equally important in regard to the amounts required to make food. Carbon dioxide fixation does not seem to be well understood across all grade levels.

Tables 17 and 18 carry evidence to show that there were significant differences both within and between grade levels for Task 8 response frequencies.

Task 9 was a free response item designed to elicit explanatory comments concerning a student's decision about Task 8. About 80% of the students gave a written response with a statement of causality. Of these, the majority (33%) cited soil as being food for plants or soil as a source of minerals (25%). Soil as a source of water garnered 13% of the responses across all grades tested. These written explanations reveal why most students thought the main source of a plant's food was the soil.

Table 19 gives a sample of the misconceptions students hold about where plants get their food. A wide variety of

Table 17

Chi-Square Analysis of Response Differences within Grades for Task 8

Grade	Response				Total
	Water	Carbon Dioxide	Soil	Air & Water	
5	f_o=45 f_e=102.75	f_o=24 f_e=102.75	f_o=265 f_e=102.75	f_o=77 [illegible]2.75	411
	χ^2≈355.5 is greater than χ^2=11.34 (3df) at [illegible]1 level.				
8	f_o=25 f_e=96.5	f_o=23 f_e=96.5	f_o=236 f_e=96.5	f_o=102 f_e=96.5	386
	χ^2≈310.9 is greater than χ^2=11.34 (3df) at .01 level.				
11	f_o=25 f_e=93.5	f_o= 8 f_e=93.5	f_o=253 f_e=93.5	f_o=88 f_e=93.5	374
	χ^2≈400.8 is greater than χ^2=11.34 (3df) at .01 level.				
14	f_o=14 f_e=51.5	f_o=10 f_e=51.5	f_o=101 f_e=51.5	f_o=81 f_e=51.5	206
	χ^2≈125.2 is greater than χ^2=11.34 (3df) at .01 level.				

Table 18

Chi-Square Analysis of Response Differences between Grades for Task 8

Grade	Response				Total
	Water	Carbon Dioxide	Soil	Air & Water	
5	f_o=45 f_e=32.5	f_o=24 f_e=19.4	f_o=265 f_e=255.2	f_o=77 f_e=103.9	411
8	f_o=25 f_e=30.6	f_o=23 f_e=18.2	f_o=236 f_e=239.7	f_o=102 f_e=97.6	386
11	f_o=25 f_e=29.6	f_o= 8 f_e=17.7	f_o=253 f_e=232.2	f_o=88 f_e=94.5	374
14	f_o=14 f_e=16.3	f_o=10 f_e= 9.7	f_o=101 f_e=127.9	f_o=81 f_e=52.1	206
Total	109	65	855	348	n=1377

χ^2≈46.15 is greater than χ^2=21.67 (9df) at .01 level.

Table 19

Representative Sample of Explanatory Written Responses (Task 9) from Students at Each Grade Level

Grade	Task No. 8 Response	Name--Task No. 9 Explanation
5	The food of plants comes from water.	Tiffany--Because the warter falls on the leaves and goe's through which feeds the tree.
		Valerie--What would the plant drink if there was no water.
	The food of plants comes from soil.	Brenda--The soil has bits of food in it and the roots find it and eat it.
		Kasay--Because when the tree or plant is planted the people put food in the soil (plant food).
		Sasha--Last year it said in our book that a plants food comes from the nurshing soil.
		Heather--Because like poatatoes and carrots come from the ground, most of the other plants that we eat comes from the ground to.
		Reid--The soil has energy from the sun.
		Tom--How can food come from air or water?
		Dawn--Plants can't walk and get food or grab it so it must come from the soil.
8	The food of plants comes from water.	Dean--This summer my dad and I planted a tree farm. And the trees wouldn't of grow without alot of water. We had to water them every day.
		Christina--You can't feed plants in a dish but when you give them water they stay alive. And that contains their food.
	The food of plants comes from soil.	Mike--Where else could it get food?
		Vance--Because it is in Books I have read!
		Jean--Vitemins come from the earth which help them grow.
8	The food of plants comes from soil.	Monica--Because the roots are down there why in the world would they be down there if there is no purpose.
		Dennis--Well the sun is the chief source but they do draw minerals and water neccessary for life from the soil but if someone asked me that question I would say the Sun.
	The food of plants comes from water and air.	Lori--There are substances and food in the air and water so when it rains, the plants get water and there are things floating in the air for plants to live on.
11	The food of plants comes from water.	Lisa--It needs the water to live--the plants get greener when it rains.
		Cindy--The plant has the ability to change water into glucose which is food for it.
	The food of plants comes from soil.	Robin--The roots go down in soil and get water and food and send it up the tree through the xylem and phloem.
		Deborah--Because I just was taught that!
		Christopher--If a farmer plants the same crop in a fild year after year and does nothing to the soil after a few years his plants will start becoming smaller and not be as productive.
		Wendy--They are all necessary items but without the soil the others are worthless. The food is got to come from the soil or people wouldn't spend so much money on fertilizer.
14	The food of plants comes from water.	Cliss--You can grow plants in water without soil but you can't grow them in soil without water.
14	The food of plants comes from carbon dioxide.	Matthew--The plants use CO_2 to produce sugars in photosynthesis, but wouldn't a better answer have been sunlight?
	The food of plants comes from soil.	Denice--The soil has a lot of vitamins and minerals in it which the plant needs to live.
		Marti--The roots is what sends food up to the rest of the plant. The roots get food from the soil.

inferences students make lead them to favor a particular option. Teachers who fail to probe would hardly be able to anticipate the wide variety of notions about how plants make food that exist within their pupil's minds.

Task 11 was designed to disclose whether students understood what the product of photosynthesis is. They were given three choices and most students (46% to 59%) across all three lower grade levels selected "proteins". The accepted answer, "carbohydrates", was picked by 37% to 41% of the aforementioned grade levels. Only the collegian sample contained more respondents choosing "carbohydrate" (51%) than "protein" (46%); the results were equivocal at best. Most students, as can be seen in Figure 10, seemed to know that photosynthesis does not produce fats.

Table 20 shows significant differences for response frequencies within grade levels but Table 21 displays a chi-square value which fails to reject the null hypothesis. Students did not appear to show much conceptual development across grade levels in this area and extant misconceptions apparently prevail from elementary school through the college level. Failure to recognize the product of photosynthesis may demonstrate that the anchoring chemical concepts necessary for meaningful learning were not in place.

Table 20

Chi-Square Analysis of Response Differences within Grades for Task 11

Grade	Response			Total
	Proteins	Fats	Carbohydrates	
5	$f_o=243$ $f_e=137.3$	$f_o=15$ $f_e=137.3$	$f_o=154$ $f_e=137.3$	412
$\chi^2 \approx 192.3$ is greater than $\chi^2=9.21$ (2df) at .01 level.				
8	$f_o=230$ $f_e=130.7$	$f_o=10$ $f_e=130.7$	$f_o=152$ $f_e=130.7$	392
$\chi^2 \approx 190.4$ is greater than $\chi^2=9.21$ (2df) at .01 level.				
11	$f_o=222$ $f_e=127$	$f_o=5$ $f_e=127$	$f_o=154$ $f_e=127$	381
$\chi^2 \approx 194.0$ is greater than $\chi^2=9.21$ (2df) at .01 level.				
14	$f_o=96$ $f_e=69$	$f_o=6$ $f_e=69$	$f_o=105$ $f_e=69$	207
$\chi^2 \approx 86.9$ is greater than $\chi^2=9.21$ (2df) at .01 level.				

Table 21

Chi-Square Analysis of Response Differences between Grades for Task 11

Grade	Response			Total
	Proteins	Fats	Carbohydrates	
5	$f_o=243$ $f_e=234.1$	$f_o=15$ $f_e=10.7$	$f_o=154$ $f_e=167.2$	412
8	$f_o=230$ $f_e=222.8$	$f_o=10$ $f_e=10.1$	$f_o=152$ $f_e=159.1$	392
11	$f_o=222$ $f_e=216.5$	$f_o=5$ $f_e=9.9$	$f_o=154$ $f_e=154.6$	381
14	$f_o=96$ $f_e=117.6$	$f_o=6$ $f_e=5.4$	$f_o=105$ $f_e=84.0$	207
Total	791	36	565	n=1392

$\chi^2 \approx 15.52$ is less than $\chi^2=16.81$ (6df) at .01 level.

Figure 10

Proportion of Students Selecting Each Option for Task 11

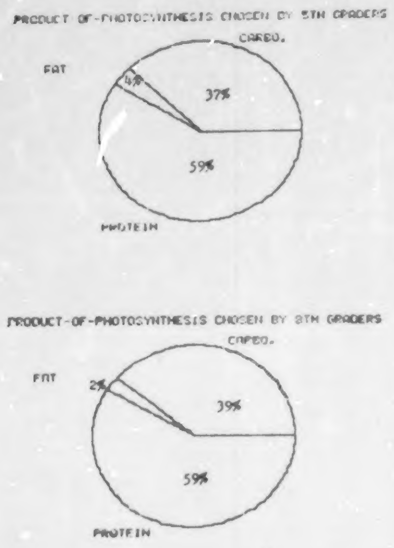
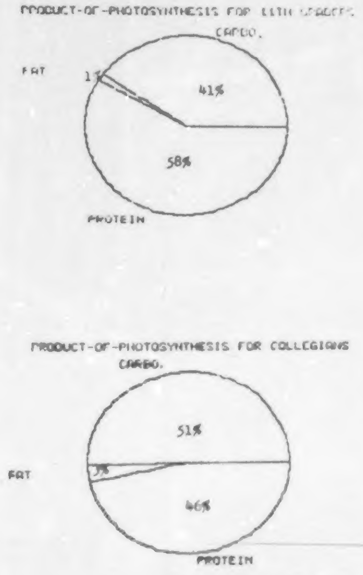


Figure 10--Continued



Analysis of Results

What Effect Does Teaching Have on the Development of the Photosynthesis Concept in Students over Time?

With few exceptions, students' concepts of photosynthesis continued to change as they moved through the educational system. Significant differences between grade levels were demonstrated by chi-square testing.

The least amount of improvement over time was demonstrated for the following concepts:

(a) the role of water in photosynthesis;

(b) the role of chlorophyll in photosynthesis;

(c) the importance of carbon dioxide as the main source of "raw material" for photosynthesis; and

(d) the "product" of photosynthesis, carbohydrates.

The results of this study support previous findings (Roth, Smith, & Lavender, no date) that students' beliefs about what plants need may be modified by instruction but "specific functional understandings" about plants and photosynthesis may often be lacking. Their conclusion on this matter (drawn from work with fifth graders) agrees with my findings across four grade levels.

Lavender and Anderson (1982) worked with college students and showed that only 6% were able to describe the basic chemical change that occurs in photosynthesis.

My assessment is that students simply do not possess the relevant concepts necessary to link the new knowledge they encounter in classroom lessons about photosynthesis to their existing cognitive structure in a substantive (meaningful) way. Such deficiencies thwart development of a more sophisticated concept of photosynthesis and reduce many potentially meaningful lessons to exercises in rote learning.

Admittedly, as Resnick (1983) points out, "naive theories will always be constructed [by students] as part of the learning process." Perhaps concepts such as photosynthesis are taught so quickly and abstractly in schools that students don't connect them well to what they already know, and subsequently, they continue to lean on their own naive explanations in spite of increased instructional time.

Are there Identifiable Misconceptions that Interfere with Learning How Plants Make Food?

The following naive ideas and misconceptions were uncovered by this study:

(1) The soil loses weight as plants grow in it.

(2) The soil is the plant's food.

(3) Plants eat minerals.

(4) Roots absorb the soil.

(5) Soil has nothing to do with plant growth.

(6) Plants feed on water.

(7) Plants get protein from the soil.

(8) Plants convert energy from the sun directly into matter.

(9) Plants get vitamins from the soil.

(10) Plants give off mainly carbon dioxide.

(11) The leaf's main job is to capture the rain and the water vapor in the air.

(12) The leaf's main job is to capture the sun's warmth.

(13) Water vapor moves into the leaf during photosynthesis.

(14) Plants take oxygen out of the air during photosynthesis.

(15) Plants grow to giant size in the dark.

(16) Plants get their food from the roots and then store it in their leaves.

(17) Chlorophyll is the plant's blood.

(18) Leaves change color because they can't breathe (just like a person's face does).

(19) The chemical that absorbs sunlight in leaves is "chlorine" or "chloroform" or "chloraseptic."

(20) Trees sleep in winter.

(21) Chlorophyll is no longer available in the air in fall so the leaf can't get food.

(22) The soil supplies most of the "raw materials" for photosynthesis.

(23) In fall, chlorophyll can't get into the leaves from the trunk any longer--a little valve in the leaf stem closes.

(24) Leaves drink in the dew.

(25) Rain goes in the holes on leaves.

(26) People put food (fertilizer) in the soil for plants to eat.

(27) Food can't be made out of air.

(28) There are things floating in the air for plants to live on.

(29) Plants change H_2O into sugar.

(30) Phloem carries water and food from the soil to the top of the plant.

(31) Plants produce protein in photosynthesis.

It may be observed that a fair number of the misconceptions listed above relate to where plants get their food. Smith and Anderson (1983) noted that the fifth graders they studied had an underlying conception of food as being materials plants take in. Roth, Smith, and Anderson (no date) divided that conception into three categories:

(1) things plants need;

(2) all the things plants take in; and

(3) particular things plants take in.

In my opinion, botanical misconceptions often arise because humans, as heterotrophs, anthropomorphize their concepts about plants. They have great difficulty imagining what it would be like to live without eating (being an autotroph).

Garden shops sell fertilizers labeled "plant food" and "weed and feed". Florists talk about "feeding" their greenhouse crops. Mothers tell their children to "give the plants a drink." All of these societal practices encourage misconceptions about how plants live (Wandersee, 1983).

Lessons about photosynthesis in school are sometimes linked to inappropriate and invalid subsuming concepts. Unless the teacher takes pains to assist the child in identifying the unscientific concepts and in correcting the misconceptions, integrative reconciliation (new learning that results in explicit delineation of similarities and differences between related concepts) will not occur. As Ausubel, Novak, and Hanesian (1978) emphasize,

> One attribute of outstanding teachers is that they have sufficient breadth of knowledge and experience with learners in their field to enable them to aid students in explicit ways to form their individual integrative reconciliations.

Resnick (1983) contends, ". . . only rarely today does teaching explicitly acknowledge children's prior theories (except to mark them wrong) or even recognize the difficult intellectual work entailed in giving them up or substantially revising them."

Novak (1977) writes, "If we do not want a definition of photosynthesis to be learned by rote, we must ascertain to what degree the associated subsuming concepts are present and developed or differentiated." Science teachers never begin with a child who is a tabula rasa. As Gowin (1981) suggests, we "begin in midstream." Knowing something about the kind of stream we're in and the hazards we may encounter makes the task much easier.

Boyer (1983) identifies water, soil nutrients, carbon dioxide, oxygen, and radiation as the major physicochemical resources of plants. This study centered on those resources in seeking to analyze selected aspects of the photosynthesis concept. The results of this study, when combined with the work of Martin (1979) and the research done at Michigan State University, give us a more detailed picture of the problems students face in learning the photosynthesis concept than we have ever had before.

Excellence in teaching science is fostered by carefully organized, theory-driven research done by committed scholars. We must continue to pursue vigorous programs of cognitive research on misconceptions in science education.

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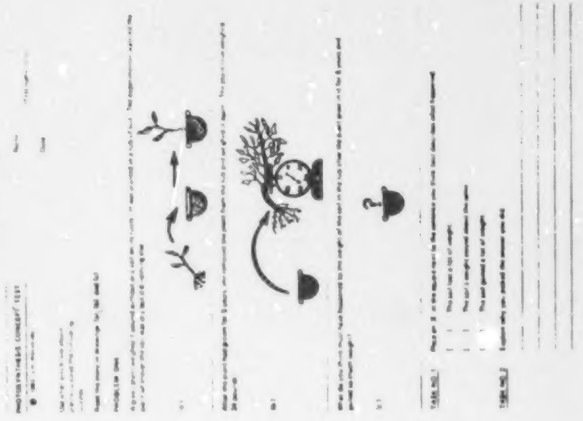
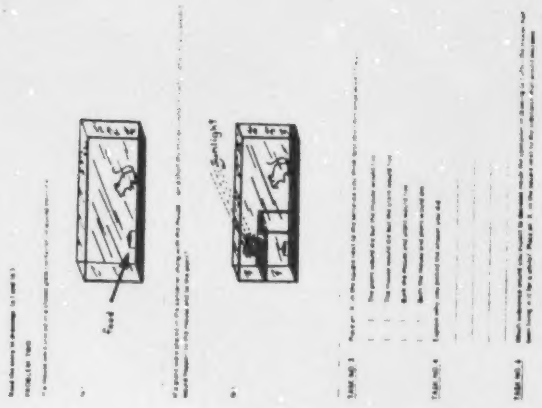
Appendix A

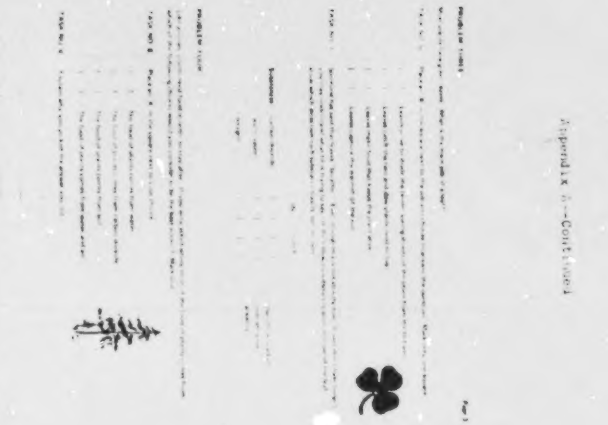
Photosynthesis Concept Test



Appendix A--Continued


Food
Sunlight?

Note. The actual test copy used by students was 30% larger.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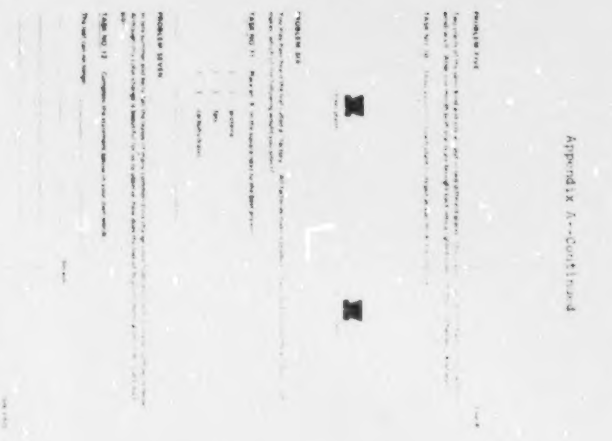
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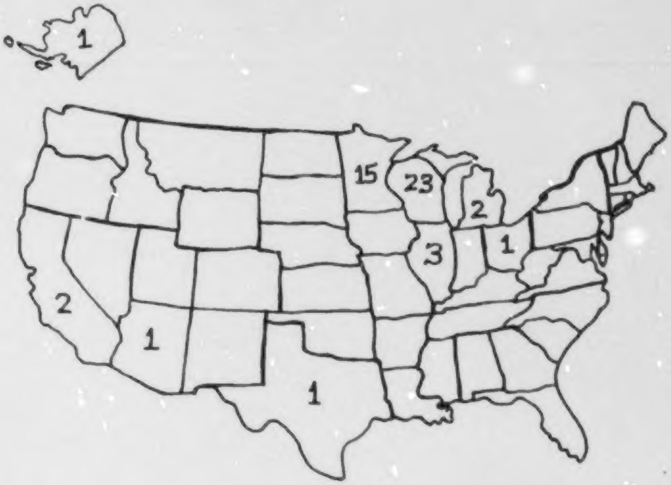
Appendix B

Map Showing the Number of Schools Participating in the Study by State



Note. Schools in the sample were selected at random from a national directory of Lutheran schools. Comparison of PCT test responses from a class of public school students and a class of private school students showed no significant differences with a chi-square test at the .01 level.

CONCEPT MAPPING: A METHOD FOR DETECTION OF POSSIBLE STUDENT MISCONCEPTIONS

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Broome Community College

INTRODUCTION

Concept mapping was studied as a method for assisting students to learn general college chemistry. Student-constructed concept maps were employed to help the students develop an understanding of each distinguishable subject area they studied and see the contribution each of these areas made to an overall, unified understanding of general chemistry.

At the beginning of the semester the instructor explained to the students the purpose and value of their learning chemistry through the development of conceptual relationships. The students were then given instructions for the construction of concept maps. These maps were included as part of the students regular assignments during the semester and the complexity of the subject area to be mapped was increased in stages as the semester progressed. As a final project at the end of the semester the students were asked to develop a concept map based on a general concept, such as "chemical composition", which was related to a major portion of the semesters subject matter.

The students were interviewed by the instructor three times during the semester using the student-constructed maps as a focal point for the discussion. The interviews were held (1) during the third to fourth week of the semester, (2) during the eighth to ninth week and finally, (3) during the last (fifteenth) week of classes.

One of the major findings of the study was that the student-constructed maps identified areas of possible student misconceptions, misconceptions which would not have been detected through normal testing procedures. Following a discussion of these areas in an instructor-student interview, the student was then able to reason to a new understanding of the area with the help of concept-map construction.

The following information presented in the poster display is an example of the instructors detection of misconceptions concerning an important chemical concept and their subsequent correction. The sequence of events took place during the eighth through tenth week of the semester.

A CLASSROOM EXAMPLE: The use of student-constructed concept maps in probing and correcting a student's understanding of intermolecular forces in the gaseous and liquid states of matter

SEQUENCE OF EVENTS—STUDENT "A"

1. DETECTION OF POSSIBLE MISCONCEPTION

The student was assigned the construction of a concept map of the gaseous state as presented in the textbook and in lecture. Chemical Principles, fifth edition, "Physical Behavior of Gases", pp. 135-158, Masterton, Slowinski and Stanitski, Saunders, 1981. The students concept map was complete and substantially correct except for the relationship shown between "molecular attractive force" and "kinetic theory of gases". (See relationship in upper right corner of student map, page 3.)

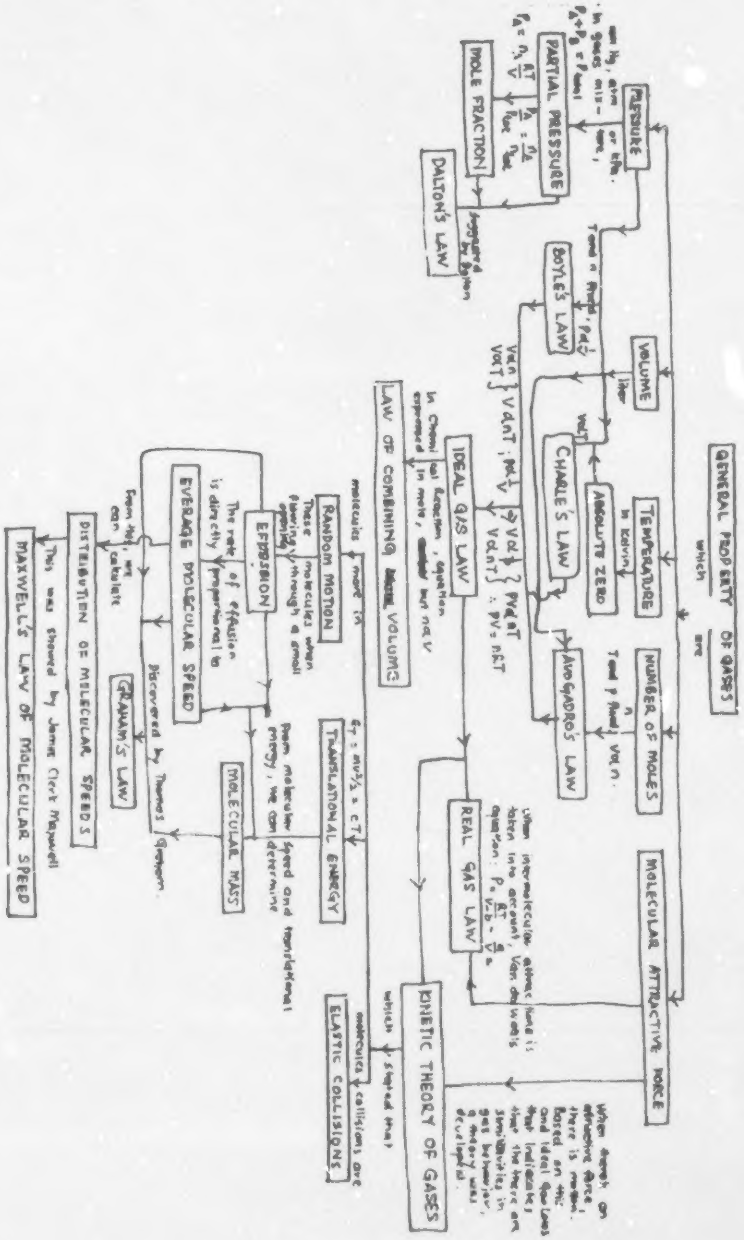
2. INVESTIGATION OF AREA OF MISCONCEPTION AND POSSIBLE ALTERNATE UNDERSTANDINGS

The student was interviewed by the instructor concerning the concept map. The relationship shown between "molecular attractive force" and "kinetic theory of gases" indicated the student understood molecular motion to be due to intermolecular attractive forces (see student concept map). This possible misunderstanding was substantial and could hinder the students subsequent understanding of the liquid and solid states. The student was questioned about this relationship (see dialogue, pages 4-6).

3. DEVELOPMENT AND VERIFICATION OF NEW UNDERSTANDING

The student was given a quiz asking for the construction of a concept map of the phenomena of vapor pressure, which involved the concepts of "intermolecular forces" and "kinetic energy of molecules". He constructed three preliminary maps prior to his final answer and showed a significant change and development in his understanding of the role these forces play in phase changes. Preliminary maps:

a. Map (a) merely showed a linear definition of evaporation. (page 7)
b. Map (b) introduced "kinetic energy of molecules" as related to the physical state of a substance. (page 7)


GENERAL PROPERTY OF GASES
which are
PRESSURE
mm Hg, atm or kPa
In gases mixtures, P_A + P_B = P_total
PARTIAL PRESSURE
MOLE FRACTION
DALTON'S LAW
proposed by Dalton
T and n const, P ∝ 1/V
BOYLE'S LAW
VOLUME
liter
V∝T
CHARLE'S LAW
TEMPERATURE
in Kelvin
ABSOLUTE ZERO
NUMBER OF MOLES
T and P const, V∝n
AVOGADRO'S LAW
V∝nT ; P∝1/V
PV∝nT : PV = nRT
IDEAL GAS LAW
In Chemical Reaction, equation expressed in mole
LAW OF COMBINING VOLUMES
RANDOM MOTION
EFFUSION
The rate of effusion is directly proportional to
EVERAGE MOLECULAR SPEED
GRAHAM'S LAW
Discovered by Thomas Graham
DISTRIBUTION OF MOLECULAR SPEEDS
This was showed by James Clerk Maxwell
MAXWELL'S LAW OF MOLECULAR SPEED
TRANSLATIONAL ENERGY
MOLECULAR MASS
REAL GAS LAW
KINETIC THEORY OF GASES
ELASTIC COLLISIONS
MOLECULAR ATTRACTIVE FORCE

DIALOGUE BETWEEN INSTRUCTOR AND STUDENT A

Instructor had marked student's concept map on the gaseous state and indicated areas of possible confusion.

I. "I said you try to say too much on that line."

S. "You say that something is incorrect, between kinetic theory of gases and molecular attractive force. Is that incorrect?"

I. "Explain to me what you mean by that, what you mean by that line that you drew between molecular attractive force and kinetic theory of gases."

S. "Kinetic theory is, I don't know, when there is an attractive force it means that the molecule must be moving---so ---is random motion."

I. "O.K. now say that to me again slowly the fact that there is attractive forces is what makes the molecules move?"

S. "Yes."

I. "Oh, I see and thats why you thought it tied into the kinetic theory of gases?"

S. "Yes."

I. "What attractive forces are you talking about?"

S. "The forces between the molecules----

I. "Go ahead--I think this will lead into something that will make this all clear to you. The attractive forces between molecules you say is what makes the molecule move."

S. "To make them stay in the gaseous state, in the gaseous state."

I. "O.K. then if I had two molecules, and this is really over simplifying it but if I had two molecules, and they were attracted toward each other, what would they be being attracted by? What would make them be attracted to each other?"

S. (very soft) "Intermolecular forces."

I. "Like what?"

S. (no reply)

I. "Haven't we talked about intermolecular forces?"

S. (long pause)

I. "What are some of the things that could lead to one molecule being attracted by another molecule?"

S. "Kinetic energy." (very soft)

I. "What does kinetic energy mean?"

S. "Moving." (very, very soft)

I. "Why does motion cause them to be attracted?"

S. (No response—24 sec.)

I. "If I had two tennis balls and they both were moving would they be attracted to each other?"

S. "I don't think so, ha."

I. "O.K. so probably motion then doesn't cause attraction. What other factors do we know about a molecule that could cause it to be attracted to another molecule?"

S. "The motion doesn't cause attraction. I thought the attraction causes motion."

I. "O.K. the attraction causes motion. What is the attraction?"

S. (No reply)

I. "I have a molecule here and a molecule here and they're attracted toward each other and start to move toward each other. Can you think why?"

S. "Charge."

I. "Charge, O.K. Remember those intermolecular forces we talked about in the book and in class. O.K. I've got this intermolecular force between these two molecules. Attracting these two molecules toward each other—what's going to happen?"

S. "They will repel—they will repel each other."

I. "Why?"

S. "Because they have the same charge."

I. "What has the same charge?"

S. "The—the—the molecule has the same charge."

I. "Well then why were they attracted? You can't have it both ways. If one is right the other must be wrong. If there is attractive forces there must be some difference in charge, right?"

S. "Right."

I. "What happens when they get close to each other if they are different in charge?"

S. "It becomes neutral—if they are different in charge."

I. "Would they keep moving or come together?"

S. "They would come together if they are different in charge."

I. "O.K. and when gas molecules start coming together what happens?"

S. "They become solid—or liquid."

I. "Right, it would condense."

I. O.K. then, if the motion of my molecule was due to attractive forces if the only reason my molecule was moving was because it was being attracted by something else—another molecule—then when it got there it would probably condense. Now what else can account for motion in a gas molecule?"

S. (no reply)

I. "What happens if I want to vaporize a liquid?

S. "You have to add some energy."

I. "O.K. and what does added energy do to molecules?"

S. "It increases their kinetic energy. It increases their motion."

I. "So the motion of molecules is mostly due to..."

S. "The kinetic energy that they have."

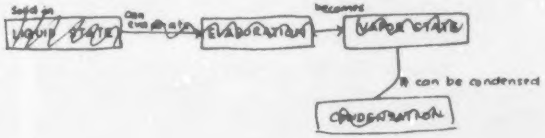
I. "That's why we call it the kinetic theory."

c. Map (c) introduced the evaporation-condensation dynamic between liquid and vapor states and related "kinetic energy of molecules" to the phase changes. He attempted to introduce "intermolecular forces" but related it as being dependent on the "kinetic energy".

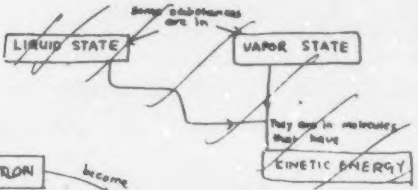
(10 pts) 1. **One of the physical properties of any liquid is its vapor pressure. Draw a concept map to show the relationship of the following concepts in understanding this physical property. You may add other concepts if they will help.**

liquid state	**dynamic equilibrium**
vapor state	**kinetic energy**
evaporation	**intermolecular forces** –1
condensation	

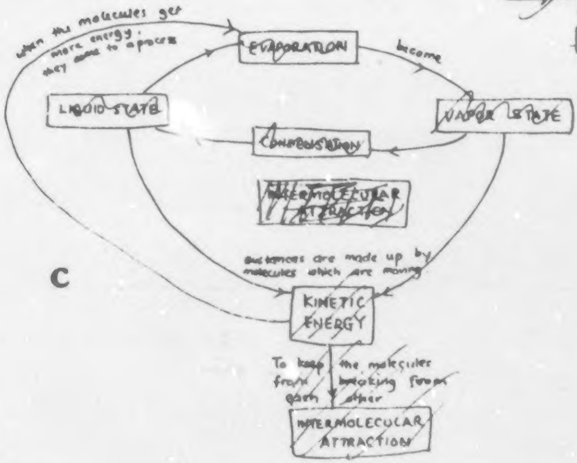
a


Solid in
~~LIQUID STATE~~
can evaporate
EVAPORATION
becomes
VAPOR STATE
it can be condensed
CONDENSATION

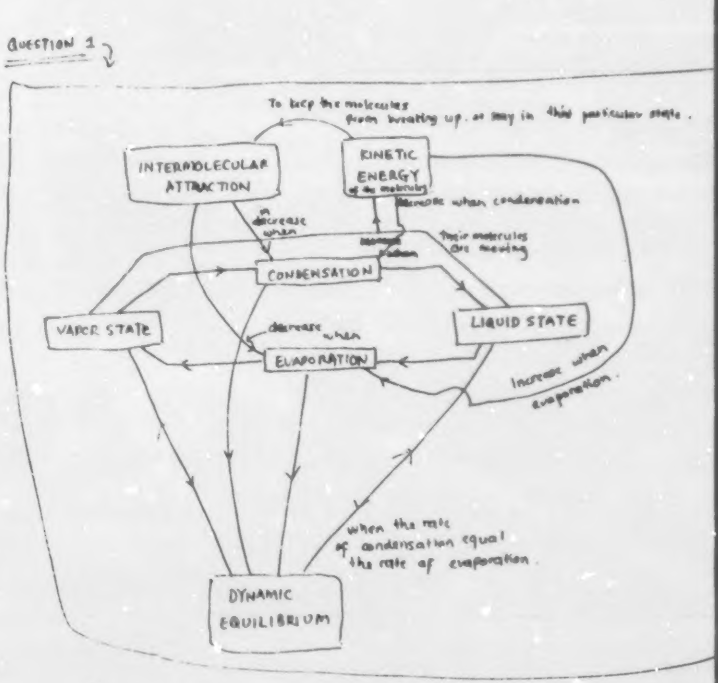
b


~~LIQUID STATE~~
Some substances are in
VAPOR STATE
They are in molecules that have
~~KINETIC ENERGY~~

c


when the molecules get more energy, they come to a process
EVAPORATION
become
LIQUID STATE
VAPOR STATE
CONDENSATION
~~INTERMOLECULAR ATTRACTION~~
substances are made up by molecules which are moving
KINETIC ENERGY
To keep the molecules from breaking from each other
INTERMOLECULAR ATTRACTION

d. In the final concept map, the student shows an understanding of the relationship and interplay between the key concepts of "kinetic energy of molecules" and "intermolecular attractive forces" and how each contributes to an understanding of the evaporation-condensation phase change. This map is the first to indicate the conceptually equal but opposing nature of the forces of "kinetic energy of molecules" and "intermolecular attraction" in understanding the dynamics of phase equilibria between a liquid and it's vapor.


QUESTION 1
To keep the molecules from breaking up. or stay in this particular state.
INTERMOLECULAR ATTRACTION
KINETIC ENERGY of the molecules
decrease when condensation
in decrease when
increase when
Their molecules are moving
CONDENSATION
VAPOR STATE
LIQUID STATE
decrease when
EVAPORATION
Increase when evaporation.
when the rate of condensation equal the rate of evaporation.
DYNAMIC EQUILIBRIUM

SEQUENCE OF EVENTS—STUDENT "B"

1. DETECTION OF POSSIBLE MISCONCEPTION

   The student was assigned the construction of a concept map of the liquid and solid state and changes in state as presented in the textbook, pages 246-269, and in lecture. The students concept map was divided into two concept maps; a concept map of "intermolecular forces" and a concept map of phase changes. (Student indicated this lack of relationship at the center of his map with arrows and the statement "discussed in the same chapter"; see page 10.)

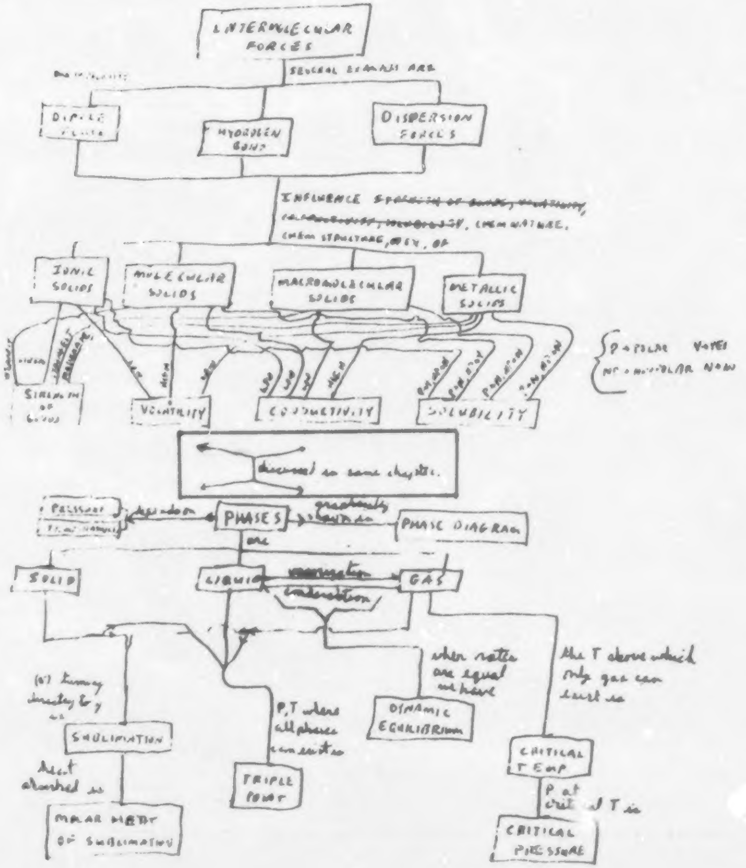
2. INVESTIGATION OF AREA OF MISCONCEPTION AND POSSIBLE ALTERNATE UNDERSTANDING

   The student was interviewed by the instructor concerning the concept map. The division the student had made in his concept map indicated he understood "intermolecular forces" as an explanation of the solid state but not important to an understanding of changes in state. This possible misunderstanding was substantial and could hinder the studentssubsequent understanding of phase equilibria. The student was questioned about this relationship (see dialogue). See pages 11 and 12.

3. DEVELOPMENT AND VERIFICATION OF NEW UNDERSTANDING

   The student was given a quiz asking for the construction of a concept map of the phenomena of vapor pressure. This involved relating the concepts of "intermolecular forces","kinetic energy of molecules" and "dynamic phase equilibrium". The concept map he constructed showed a significant change and correction of his previous inadequate understanding of intermolecular forces. The concept map indicates the students recognition of the importance of "intermolecular forces" along with the "kinetic energy of molecules" in understanding the dynamics of phase equilibria. See page 13.

JEF:es


INTERMOLECULAR FORCES
SEVERAL EXAMPLES ARE
DIPOLE FORCES
HYDROGEN BOND
DISPERSION FORCES
INFLUENCE ~~STRENGTH OF BONDS,~~ ~~VOLATILITY,~~ ~~CONDUCTIVITY,~~ ~~SOLUBILITY~~, CHEM NATURE, CHEM STRUCTURE, PHY. OF
IONIC SOLIDS
MOLECULAR SOLIDS
MACROMOLECULAR SOLIDS
METALLIC SOLIDS
STRENGTH OF BONDS
VOLATILITY
CONDUCTIVITY
SOLUBILITY
POLAR VOTES
NONPOLAR NOW
discussed in same chapter.
PRESSURE
TEMPERATURE
dependent
PHASES
graphically shown in
PHASE DIAGRAM
are
SOLID
LIQUID
GAS
evaporation
condensation
when rates are equal we have
DYNAMIC EQUILIBRIUM
the T above which only gas can exist is
CRITICAL TEMP
P at critical T is
CRITICAL PRESSURE
P,T where all phases can exist is
TRIPLE POINT
SUBLIMATION
heat absorbed is
MOLAR HEAT OF SUBLIMATION

DIALOGUE BETWEEN INSTRUCTOR AND STUDENT B

I. "Did doing concept maps help you bring ideas in different chapters together?"

S. "Chapter eleven I did in two parts. I didn't put it together. It was in the same chapter but there didn't seem to be any major connection or any reason they should be connected."

I. "You show a relationship between intermolecular forces and types of solids."

S. "These are the forces that make the solids—isn't that right? This is all the stuff that was in forces part of the chapter."

I. "Sort of....what do you mean by a force—an intermolecular force?"

S. "Forces that attract between the molecules, I think?"

I. "O.K., now does that have anything to do with phase changes?"

S. "Well, phase changes would be more due to an increase in kinetic energy."

I. "Let me put it another way. Would it have anything to do with what phase something is in at a given temperature?"

S. "That would depend on the pressure. You mean would intermolecular force have anything to do with it?"

I. "Yes."

S. "No, I wouldn't think so, not really—I would think it would be more a function of the pressure."

Interviewer asked about "volatility"—student had shown for solids. Student recognized it meant changing to vapor state.

I. "So it is a change in state, right?"

S. "Oh, O.K., I didn't see that."

I. "Why would it be low or high (volatility)?"

S. "That would depend on the forces."

I. "If a substance has a high vapor pressure, what does that tell about its intermolecular forces?"

S. (soft, hesitant response) "Ah...they're strong...if high vapor pressures have to be strong....don't they?"

I. "Good guess, but wrong."

S. "Wrong? If high vapor pressure?"

I. "What is vapor pressure?"

S. "Pressure of vapor—amount of vapor....Oh, O.K., if high vapor pressure would be weak intermolecular forces." (strong, positive)

I. "If compared to things with different vapor pressures?"

S. "The higher vapor pressures would mean weaker intermolecular forces, so a macromolecular solid would have a low vapor pressure."

I. "So all these phase changes would depend on what?"

S. "On the molecular forces."

I. "O.K."

S. "Um Hum".

I. "So, do you see tie between two maps...?"

S. "Yes—no intermolecular forces in gas very strong in macromolecular solid."

I. "Do concept maps show me what you understand?"

S. "Yes, it does. I just feel bad I didn't know what to do about that one. But it was O.K. It showed I didn't understand intermolecular forces good enough to do the concept map.

At the end of the interview:

I. "Did the interviews concerning the maps help you learn?"

S. "Definitely cleared up things that I didn't understand like the intermolecular forces and phase changes—that definitely. I could now make one good map and play these two together much better."

Just Putting Down Numbers: The Child's and Teacher's Definitions of "Learning Mathematics"

Harry Osser, Floyd Durmin and Molly Sorensen
Queen's University

Carol: I'm not really learning anything... I'm just putting down numbers.

If, as Lefrère (1981) suggests, we pose the question "Who confers meaning on school work?" one answer, given the unequal distribution of authority in the classroom, is that it is the teacher who imposes *her* meanings on classroom activities. She is, afterall, essentially in control of the lesson, has the right to define the subject by designating particular work as important and valuable, and to strongly suggest to the pupil that certain procedures have to be followed in doing the work. In the case of mathematics this interpretation of classroom life appears to be especially clear. Ormell (1978), argues that the average teacher learns rather passively as many mathematical rules as possible, as this is personally more cost effective than struggling to be mathematically creative. The teacher then teaches mathematics unreflectively, as she had previously learned it "stiffened suitably with greater emphasis and firm authority" (p. 112) This results in an invitation to the children to "circulate among themselves the much simpler operational rules which underly the approved formulism" (p. 109). The suggestion here is that pupils also define and thereby confer meanings on school work which do not necessarily coincide with those proposed by the teacher. In other words, *both* the teacher and the pupils confer meanings on their school experience.

This interpretation of the pupil as an interpreter of experience receives general support from the psychological theory of human action espoused by Von Cranach (1982). He views *the social nature of action* as being essentially composed of goal-directed action. He argues that "In an elaborated form, the concept implies a two-fold relationship: society controls and directs GDA, and in performing socially directed, meaningful acts, the actor (partially) constructs society." (p. 42). In discussing *degrees and qualities of influence*, Von Cranach proposes that *external* control "influences the course of action through environmental devices and exercise of power", and *internal* control "by implanting into the individual (in the course of socialization) cognitive and motivational/emotional structures (for example, scripts, rules, knowledge, values, needs etc.) which guide his action." (p. 42).

If Von Cranach's theoretical statements about the social and individual sources of goal-directed actions were acceptable, then one could predict that pupils would inevitably develop alternative conceptions of "school mathematics", quite distinct from the authorized versions. The meaning of the child's "alternative conception or framework" is however problematic. We are very far from having an adequate account of the child's interpretation of "school mathematics". We do have useful methodological proposals for the development of such an account, for example, Driver and Easley (1978) recommend that we undertake a close examination of the content of the child's ideas, strategies and ways of thinking about school work, in order to understand the "essential individuality of learning" (see also Marton, 1981 for another set of useful recommendations).

A study of the meaning of "learning mathematics"

The following is an account of a part of the information generated by an interview and observational study of a teacher and her 9 pupils in a special class for children with learning problems. The major goal of the study was to analyze the role of different types of knowledge in children's mathematical performances. Another allied goal of the study was to provide some information on the pupils' and teacher's definitions of "learning math". For example, the pupil might on some occasions operate with a rather passive strategy in school learning where much of the material provided by the teacher is memorized with minimal understanding. By contrast, the pupil on other occasions might adopt a rather active strategy in an attempt to comprehend the relations between the elements of a classroom task. The pupil using a passive strategy may be taking up (or have had thrust upon him or her) a dependent learning role, so that the pupil simply acts as a reproducer of the teacher's, or other pupils', ideas, values, and problem-solving strategies; whereas the pupil using the active, creative strategy is likely to have an independent learning role, and to be an autonomous producer or, with the teacher or other pupils, a co-producer of knowledge.

As mentioned, one goal was to examine the extent to which pupils take up the strategies formulated by the teacher as part of her definition of "learning math". In the following interview with the teacher, the focus is on the procedure of "checking" as an instance of monitoring the organization of work. The relationships between monitoring and problem-solving is analyzed by Von Cranach (1982) thus: "social meaning extents social control by influence on cognition, cognition directs, regulates and monitors behaviour, behaviour (as monitored) acts back on cognition" (p. 49). She describes how she teaches pupils to check work and comments on their fidelity in following her recommendations.

I: Do they check their work? Are they supposed to check their work?

T: I have taught most of them how to check their own subtraction questions by adding the bottom number with the answer to get the top one. Basically it's just a visual check. "Six divided by two. I have six put into groups of twos. I'm not going to get three, or twenty eight groups. I'm not going to get eighteen and I'm not going to get twelve. It doesn't make sense. I have to get a smaller number." Just usually checking to make sure if it makes sense or not. "If mother had five cookies and she gave away four, how many is she left? She can't possibly have nine."

I: You were saying that they do this or they don't do this?

T: They're encouraged to do it.

I: And to what extent do they try to do that?

T: I don't think that many of them do it. They simply get their work done and hand it in and go on to something else. Get some free time or whatever have you. It's simply "let's get it done." There are some that try to get their work right but they won't check it to see if they have them right or have answered all the questions. This happens quite often. I'll call them back and say "You didn't answer this question. You left that one out, you didn't do this one, what was the lesson?" "Oh, I didn't see those." So they didn't go back to see if they had everything down. "Did I have seven questions to copy off the board? Did I copy seven down? Did I copy five down?"

I: So there's two kinds of checking that they are not always doing. One is just to see that you've completed the actual work, that you've put answers down or copied all the problems down that you were given. And the other is to see whether you've done the work properly, when you actually did it?

T: Right. If you allow them they just don't do it. They think basically "I've got to get my work done and handed in, let the teacher check it over. Then if I get the work corrected, all right! ..."

The following are samples from the interviews with two female pupils, P_1 (Terry, 8 years) and P_2 (Carol, 11 years):

I Do you ever check your work?

P1: No. I try to, but I just make the same math questions much worser, so I just leave them alone.

I: Oh, what do you mean that you make them worse?

P1: Like if I hand 'em in and I corrected them, right? Then she says "That one certainly isn't that." Say I handed that in and it was ten hundred, and she says "That wasn't it." I was wrong.

I: Do you think sometimes you have them right and then you change them when you check?

P1: Well, I never check no more because I used to get them wrong. Now I sort of get them wrong the same way.

I: Do you ever check your work?

P2: No I just look over it. Well when we're supposed to, like, um when Mrs. W. was here we, we um did this kind of thing and she would put the answers up on the board and we would check them by ourselves and that's fun 'cause I like doing that.

I: Oh I see, you mean you would check to see if your answer was the same as hers?

P2: They would show the real answer, the right answer, on the board. If you check over somebody else's work and you'd give, we did that last year and we passed over some. You take one person's work and you check over it to see if you got all your work right. You would take your own paper and check over.

Terry does not appear to share the values that the teacher attaches to checking, nor does she understand the basic procedures for checking. She has apparently tried repeatedly to arrive at the "right" answer in the past without success, consequently she has completely given up on checking. Carol on the other hand, agrees that there is some value in checking but her definition of it is very different from the teacher's. "Checking" to Carol simply means comparing answers to the teacher's "right" answer, or to other pupils' answers. The two pupils seem to be operating with a generally passive learning strategy; paradoxically the selection of a "passive" strategy is evidence of a more comprehensive creative strategy to maintain personal autonomy.

There is some support in these results for the proposition that in order for these children to make their school work meaningful, as Ormell (1978) claimed, they had to reject the teacher's suggestions of appropriate strategies, using instead their own "simpler operational rules", and thereby were in disagreement with a part of her definition of "learning mathematics". This study provides just a few details of the complex nature of the children's interpretive frameworks. To complete the picture, as Marton (1981) states, would require the exploration of the beliefs, values, strategies, organizing principles and goals which pupils bring to classroom learning situations.

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MISCONCEPTIONS OF ALGEBRAIC SYMBOLS: REPRESENTATIONS AND COMPONENT PROCESSES

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Southeastern Massachusetts University

The goal of the research described in this paper is to isolate the cognitive difficulties that prevent students from solving word problems requiring translation of quantitative relationships given in natural language and/or pictorial form. We will describe empirical work that probe the underlying cognitive representations of these quantitative relationships and the components of the processes involved in translating from one representation to the other. Our starting point was a type of translation task that has come to be known as the "students-professors" problem:

> Write an equation using the variables S and P to represent the following statement: "there are six times as many students as there are professors at this university. Use S for the number of students and P for the number of professors.

Clement and associates (Clement, 1982, Clement, Lockhead, & Monk, 1981) demonstrated that this is a surprisingly difficult problem for most undergraduates; error rates are typically over 50 percent and approximately two-thirds of the errors are reversed equations, "6S = P." Furthermore, the difficulty of the problem does not seem to be due to simple lack of concentration or misreading of the problem. Simple manipulations such as giving students cues to pay attention or to focus on the literals as numbers or changing the wording of the problem have little effect on performance (Clement, Lockhead, & Monk, 1981, Wollman, 1983). Also, attempts to teach students to correct their misconceptions by focusing in various ways on quantities that could be substituted for the literals have met with mixed success. Rosnick and Clement (1980) found that students would change their answers to the correct equation but they still misunderstood the underlying concepts. Wolman's (1983) training techniques also helped students to change their equations, and in one instance they generalized this learning to a new equation. He did not, however, check their understanding by follow-up interviews designed to test how deeply they understood the problem after training.

Clement and his collaborators, by means of extensive protocol analyses, identified several strategies used in solving problems of this sort (which we will call target problems). Students who correctly solve such problems interpret the algebraic symbols correctly. They understand that literals (S and P) are variables that stand for sets of numbers, that the constants (6 and 1) are multiplicative coefficients and that the equals sign stands for equality of the numbers so represented. This allows them to set up the problem correctly--they focus on how to make the expressions on the two sides of the equation quantitatively equal. This, as the protocols make plain, is an active process.

Clement et al. also identified two strategies that lead to reversal errors. In both cases students evidence misconceptions of the algebraic symbols. The literals are taken to stand for the real-world entities (students and professors). The "6" acts as an adjective modifying the adjacent noun "students" and the equals sign is short hand for the natural language phrase "is" or "corresponds to." In one of the strategies Clement identified, *the syntactic translation strategy*, students simply mapped the order of key words in the problem statement directly onto the pseudoalgebraic reversed equation. In the other, *the static comparison strategy*, subjects appeared to compare the relative sizes of the groups of students and professors, using the symbols of their pseudoalgebraic equation to represent this size comparison.

In the syntactic translation strategy students are clearly mapping directly from a linguistic representation (based on the written problem) to a pseudoalgebraic one. In the static comparison strategy the underlying representation is not so clear. Clement thought it was also linguistic and characterized it as semantic. Nevertheless, both the Clement group clinical interview and our own revealed that some students construct concrete images that also represent static comparisons. Thus, the natural representations underlying the static comparison strategy might be either linguistic or imagistic.

Linguistic vs. Imagistic Representations

Our first experimental goal was to explore the relative roles of linguistic and imagistic naturalistic representations. Kaput (1982) demonstrated the independent role of images in fostering errors. He gave 422 undergraduates a target problem with or without a concrete picture depicting the static comparison. As expected, the percentage of correct responses decreased from 60.4% without the picture to 37% with the picture. The effect was even more pronounced for a mathematically more experienced subsample (77% to 43%). The effect of the picture, however, was not primarily to increase the frequency of reversals. Rather, subjects exposed to the pictures exhibited a wide mix of other errors. If we assume that student-generated internal images operate in the same fashion as externally provided pictures, we can conclude from this study that imagistic as well as linguistic representations decrease the probability of solving target problems, but that the errors they produce are different. Thus, students using the static comparison strategy described by Clement may be using either linguistic or imagistic representations and only linguistic representations evidently lead to reversal errors.

We next undertook an experiment to test several of these implications (Sims-Knight & Kaput, 1983). First, if both imagistic and linguistic representations interfere with solving these problems, it suggests that their commonality--as two kinds of *natural* representations--is paramount in this context. Thus, we hypothesized that any version of the target problem that embedded the quantitative relationship strongly within a natural cognitive representation would produce higher error rates. Second, we hypothesized that there should be different patterns of errors characteristic of linguistic vs. imagistic representations. Third, we wished to test explicitly that student-generated images operate in the same way pictures did.

To test these hypotheses, we systematically manipulated the content of parallel versions of target problems. Clinical interviews involving different versions of the target problems suggested several dimensions that might affect the probability of solving the problem correctly or influence the type of error. One is *familiarity* of the quantitative relationship, e.g., the 5 to 1 ratio of finger pieces to palm pieces in a glove is numerically familiar, whereas the particular ratio of 6 students to 1 professor is arbitrary and concocted for that particular problem. Second is *imageability* of the entities that are quantified in the given quantitative relationship, e.g., pigs and cows are imageable whereas months and years or the gallons of gasoline in a particular gasoline purchase are much less so. Third is *patterning* of the elements in a given quantitative relationship involving imageable elements. Images may or may not exist in a ready Gestalt, e.g., fingers to palm pieces in gloves vs. pigs and cows. We predicted that problems involving quantitative relationships that are more firmly embedded in a subject's natural representation system (familiar quantitative relationships; imageable quantitative relationships, particularly patterned images) would be more difficult to solve, since it would be more difficult to transform the quantitative relationship to the representation system of algebra. We also predicted that imageable content should produce different errors than nonimageable content.

These problems were given to 266 third and fourth year secondary students who either had completed or were in the last month of their first algebra course and to 181 first year secondary students who were in their last month of their first year of algebra. Student responses were coded for correctness and for the presence or absence of eight kinds of errors. Each response category was submitted to an analysis of variance. We will concentrate on reporting the results for the older sample because, while the results for the younger group were similar, they were subject to floor effects (their average rate of correct responses was ony 9%).

Only one of the independent variables, familiarity of the quantitative relationship, influenced correct responses--in the predicted direction. Nonfamiliar quantitative relationships led to significantly more correct responses than familiar quantitative relationships.

The eight errors formed two consistent patterns of results. Three kinds of errors (reversal and two other kinds of errors) were more frequent in problems involving familiar quantitative relationships and nonpatterned, nonimageable quantitative relationships. The other five kinds of errors were more frequent in tasks involving nonfamiliar quantitative relationshps or which stimulated a patterned image. Two combined variables (which we called Type A and Type B, respectively) were created by disjunctive combination, Analysis of variance on the combined error types confirmed the pattern just described.

Both the intrinsic characteristics of the error types and the manipulation of task parameters point to a distinct difference in cognitive representation underlying the respective response types. The findings with respect to Type A errors (the most prevalent of which are reversal errors) are consistent with our earlier hypothesis that they are linguistically based. They were less frequent on problems that encouraged an integrated, patterned image than on problems that did not encourage such imaging. Also, students were asked follow-up questions regarding the representations they used to solve the problem and these also confirmed that Type A responses were less likely to be the result of concrete imaging. Type A errors all involved a complete equation with both variables represented, which we would expect if students are generating a sentence representing the quantitative relationship. Also, they were more frequent on tasks with familiar quantitative relationships (e.g., 5 pennies equal 1 nickel) whether or not an image was also evoked (e.g., finger pieces in a glove); such a familiar quantitative relationship is likely to be encoded linguistically whether or not an image is also generated. Thus we conclude that Type A errors seem to result from linguistic representations.

In contrast Type B errors seem to reflect attempts to map images to algebra. They were more frequent for patterned quantitative relationships, in which the quantitative relationships were embedded in Gestalts, and for nonfamiliar quantitative relationships, where subjects did not have ready linguistic representations. Type B errors also do not involve complete representations of the linguistic form used in the given problem although most still involve the juxtaposition of a number and a letter (6S).

Thus this study demonstrated that students have difficulty in translating from both linguistic and imagistic representations of quantitative relationships to algebraic equations, especially in their misuse of the phrase "6S," which occurs in both types of error. When a conflict between these natural representational systems and the algebraic representational system is minimized, as it is in problems with unfamiliar quantitative relationships, then more students can make the necessary transformation. This confirms that the difficulty lies in mapping from natural representations to mathematical ones (Clement et al., 1981).

Although linguistic and imagistic representations both interfere with the proper algebraic symbolization, these data also suggest that linguistic representations are the more important form of error educationally. Type A errors are much more prevalent than Type B erros and the incidence of Type B responses decreases during the secondary school years, whereas those of Type A errors do not.

Developmental Analysis of Transformation Errors

If one traces the developmental roots of quantitative reasoning, it becomes clear that the roots of quantitative reasoning within natural representational systems develop prior to and thereby independently of understanding of mathematics. Nesher and Schwartz (1982) characterized initial development of quantitative understanding as relational in the linguistic sense of the term. That is, numbers are first used as modifiers of nouns, as answers to questions of how many or how much. As preschoolers work with quantified situations within their environments, they develop computational abilities within natural representational systems (e.g., Cooper, 1983). By the age of 5 to 6 years, before most children are exposed to instruction in arithmetic, they are well on their way to understanding addition and subtraction quantitatively (rather than merely qualitatively, in which the exact amounts added or subtracted are ignored). By 7 to 8 years their reasoning with natural content is fully quantified.

In formal school arithmetic, numbers become objects in their own right--nominals in the linguistic sense, e.g., the number "6." The number "6," as a thing, acquires properties of its own, e.g., it is not

prime, it contains 2 and 3 as factors. This enormous expansion to include a second, nominal range of meanings on top of the relational-adjectival meanings is *not* accompanied by any change in its written or oral designation. Moreover, in doing numerical word problems the child must use both meanings, shifting from a natural language modifier usage ("Johnny has 6 apples and gives away 2 apples. . . ") to a nominal usage in choosing and then executing the appropriate arithmetic operation ("6 - 2"), and then back to the adjectival use in giving the answer "4 apples." These two distinct systems of quantitative reasoning form the basis, we believe, from which difficulties in the interpretive use of algebra flow (Kaput & Sims-Knight, 1983).

The double use of numbers appears to produce few problems in addition and subtraction, since the calculations yield the same result whether the numbers are considered nominal or relational. When multiplication is introduced, however, the seeds of conflict between the two systems are laid: 6 times 11 is taught as shorthand for "6 11's," i.e., "11 + 11 + 11 + 11 + 11 + 11." In this case ("6 11's") the linguistic representation of the nominal (arithmetic) use is exactly the same as the adjectival use of quantitative reasoning within a natural representational system, as in 6 of a kind (11's, apples, etc.). Later, when coefficient multiplication is introduced in algebra, the same situation obtains because it is usually introduced in the same way, e.g., "6x" stands for "x + x + x + x + x + x" and can be read "6 x's." Although such double meaning is by its very nature ambiguous, *it will lead to error only when the two meanings lead to different answers.*

When the literal is uninterpreted as a quantity or when a specific number is substituted for the literal, both the adjectival ("6 x's") and the nominal ("6 times the quantity x") meanings of the multiplicative relationship produce the same answer and are thereby legitimate.

Conflict arises when students are asked to interpret their algebra beyond the analytic world of mathematics,i.e., when the numbers involved stand for quantities "in the world." Under these circumstances the adjectival interpretation of algebraic expressions ("6S") can be confused with the adjectival use of quantifiers in natural representations ("6S" as shorthand for "6 students"). The net result is the persistent "6S" error syndrome, either in reversed pseudoequations or other pseudo-algebraic statements. Lastly, this overlap and resulting confusion is perpetuated and deepened by the common and legitimate use of pseudo-algebraic equations to represent equivalences between units of measurement, as when "3F = 1Y" is used to stand for "three feet are equivalent (usually read 'equal') to one yard." Of course, there is associated with any such equivalence a "reversed" genuine algebraic equation of the form 3x = y where "x" stands for the number of yards in whatever might be measured and "y" stands for the number of feet.

This analysis is consistent with our earlier conclusion that the difficulty of target problems is one of mapping a quantitative relationship represented linguistically or imagistically onto the algebraic symbol system. It further specifies the problem as one of mapping inappropriately from an adjectival use in which the object (represented by the literal) is nonquantitative ("6 students') to one in which the object should be a quantity ("6 x's" or "6 11's"). The probability of such inappropriate mapping is increased when the natural representation is highly salient, as it is with familiar quantitative relationships. This suggests that one important ingredient in solving target problems is the ability to understand the differences between natural and algebraic representational systems and to make the necessary transformations from one to the other. This may not be the only ingredient in solving target problems, however. Assuming that the best defense against being vulnerable to such slippage is a firm understanding of algebra, it may be that the students who have the best grasp of the quantitative meaning of literals (variables or potential placeholders for a quantity) would be least vulnerable to such errors.

Our argument here is analogous to the Piagetian explanation for the development of concrete operations: when children's inferential structures are well enough developed, they are no longer vulnerable to the conflict produced by the contrary perceptual information. During the transition period, when their concrete operations are developing, the salience of the perceptual conflict affects the probability of their responding inferentially.

Componential Processes in Solving Target Problems

The goal of our next study (Sims-Knight & Kaput, in preparation) was to identify component skills involved in solving target problems. To do this we devised a problem set that potentially measured (a) skills at transforming quantitative knowledge between natural representational systems (linguistic and imagistic) and abstract symbolic systems (primarily algebraic or graphical) and (b) algebraic skills.

Because the target problems involve proportional reasoning (as evidenced by clinical interviews) and because development of proportional reasoning ability has been associated with the development of formal operations, we also included a variety of kinds of proportional reasoning problems to enable us to measure its role in solving target problems. We hypothesized that it was a precursor skill, but that it would not help explain individual differences in college students' abilities to solve such problems. Our reasons for this follow. First, numerical problems parallel to the target tasks (e.g., "If there were 54 students and 9 students for each 2 professors, how many professors were there?") are solved by almost all students (Clement, Lockhead, & Monk, 1981, Wollman, 1983), indicating that *numerical* understanding of the given proportional relationship is not the issue nor is an ability to perform straightforward numerical reasoning based on this understanding. Second, most research (e.g., Brainerd, 1978; Kurtz & Karplus, 1979; Siegler, 1976) shows that the ability to solve numerical, paper and pencil proportional reasoning tasks develops during the secondary school years.

We presented 29 problems in three different orders to a heterogeneous group of 147 university students and to a more homogeneous group of 138 engineering technology freshmen. An additional set of 27 problems was solved by a subset of 68 of the engineering technology students.

We analyzed the main set of 29 problems for each sample separately. After examination of the intercorrelation of these problems and initial factor analyses, we reduced the set of problems to the 17 most highly correlated problems by application of simple structure criteria. We then refactored the reduced set using a principal components analysis with iterations and a quartimax rotation.

Insert Table 1 about here

Two major factors emerged (see Table 1). Factor 1 represents the major portion of variance as one would expect with a quartimax rotation (79.7 and 71.0 percent of variance for the unselected and engineering students, respectively). Factor 2 accounted for a smaller but still significant proportion of the variance (20.3 and 29.0 percent for the unselected and engineering sample, respectively). Similar factor structures were obtained for both samples although the engineering students found the problems easier.

All the problems that had their primary loading on Factor 1 required a transformation between a "natural" external representation (a natural language statement or a picture) and an abstract mathematical representation (either algebraic, graphical, or diagrammatic). They included but were not limited to proportional reasoning problems. Thus Factor 1 appears to reflect a general ability to translate between representational systems.

Factor 2 was best defined by the Vallapart problem (borrowed from pilot work done by Clement and Lochhead), a variant of the target task in which the equation is given and the subjects must interpret it and make inferences from the interpretation. The two target tasks had their primary loading on Factor 2, but they also loaded substantially on Factor 1, particularly for the heterogeneous sample. Although the Factor 2 problems were primarily algebraic, they were only a subset of the algebraic problems. Algebraic problems that failed to load on either factor included some instances of the following types: (a) transformations between graphs and algebra, (b) problems that required understanding of algebraic variables, (c) problems that required understanding of the syntax of algebra, and (d) word problems involving use of unknowns.

Thus, the two major components in this problem set were a broad transformational ability and a more specific ability involved in the target problems. Since the target problems loaded substantially on both factors, it seemed reasonable to conclude that both abilities are involved in solving the problems. To check out this conclusion, we computed a homogeneous scale of the problems that had the highest loadings on Factor 1 and correlated that score with performance on the target problems. Contrary to our predictions, the correlations for both samples were insignificant. Thus these data support the notion that transformational reasoning is a skill of potential generality and usefulness, but they do not provide evidence that it is a major predictor of performance on the target problems.

The additional problem set given to 68 engineering technology students included arithmetic problems and algebra problems. We produced three scales from the two problem sets available from these students--the transformational scale described earlier; a scale composed of uninterpreted algebraic problems (manipulation and production of algebraic expressions), which we called algebraic skills; and a scale of algebraic problems involving complex symbolization skills (primarily algebraic variables). These scales were stepped into a multiple regression in their presumed developmental order (the order in which they are listed). The criteron was performance on the target problems. In this analysis, only the algebraic skills predicted performance on the target problems. This supports our second hypothesis, that having a firm grasp of the algebraic symbol system is involved in being able to produce an algebraic formula that correctly describes a quantitative relationship. The skills required, however, do not appear to be a sophisticated understanding of algebraic variables, but rather the more primitive skills involved in using literals as unknowns.

The third facet of this study was the exploration of the role of proportional reasoning in solving target problems. Our results indicate that proportional reasoning problems are not all the same. The basic quantitative proportional reasoning problem (see the above example by Clement et al.) was not statistically related to proportional reasoning problems that involved a transformation from a visual representation (see the letter problem on Table 1). The latter loaded highly on Factor 1, while the former did not. The proportional problems requiring a nonalgebraic transformation did correlate moderately with the target problems (proportional problems requiring an algebraic transformation). This pattern of results for the three kinds of proportion problems suggests that the transformational component exerts a more important influence than the proportionality component.

Training Component Processes

This componential analysis suggested that three components--ability to transform across symbol systems, algebraic skills, and complex proportional reasoning (involving transformations)--might be involved in solving target problems. The correlational approach employed in the study just described is very valuable as an exploratory tool, but is inadequate to discover what skills actually determine performance on target problems. This, of course, is because students good in one math-relevant skill tend to be good in other relevant skills. Algebraic skill may better predict target performance simply because it shares more of the variance of "general mathematical abilities" rather than because strength of algebraic skills actually determines success in solving target problems. A formal experiment better addresses the causal question. Janice Yee undertook just such a study under our supervision. She gave to college students 12 problems of each type with written corrective explanation. Control subjects were given comparable amount of experience solving quantitative problems (unlike those in the training conditions) without feedback. The entire procedure took about 3 hours. Unfortunately, not all the training conditions were wholly successful. Her criterion of success in training was perfect performance on 3 consecutive problems. Although 42 of 45 subjects reached this criterion on proportional training and 40 subjects reached criterion on algebraic skills training, only 19 reached criterion on transformation training. Perhaps because of this insufficiency of training, the training subjects failed to learn to solve target problems to a greater extent than control subjects.

In spite of the failure of our experimental strategy, we were able to carry out correlative analyses. We first excluded all subjects who were initially successful in solving target problems (who had correctly solved 2 of 3 pretest target problems). We then divided the remaining training subjects into two groups, those who reached criterion on all three training conditions and those who failed to reach criterion on at least one training condition. Those who reached criterion on all three conditions were much more likely to solve at least 2 of 3 target problems (26%) than those who did not (7.7%), $\chi^2(1) = 4.98$, $p<.05$. Of course, those who did succeed in reaching criteria were most likely "better" in mathematics and this probably contributed to their subsequent success in solving target problems. Nonetheless, these subjects all "failed" their pretest, but evidently did learn something during training that facilitated their posttest performance.

This study also provides new information about the role of each component. Skill at solving proportions is not sufficient to solve target problems--almost all subjects exhibited this skill by the end of training (as would be expected from previous research), but many still failed to solve the posttest problems. These results are also consistent with the hypothesis that skill at solving proportions is a necessary condition, since all students who solved the posttest problems had reached criterion on that form of training. This is not a necessary conclusion, however, because we did not establish that students who failed to learn to solve our type of proportional problems would also be unable to solve target problems. A similar pattern held for algebraic skills training except that 1 subject who failed to reach criterion on algebraic skills training did solve the posttest problems. Difficulties in transformation reasoning was far more resistant to training than were the other two component skills. This finding confirms Rosnck and Clement's (1980) conclusion that difficulty in mapping across representational systems is deep seated and difficult to overcome during a relatively brief training. Because of the differential difficulty of transformational training compared to the other two types of training, it was transformational training that contributed most to the difference between those who reached criterion on all three training problems and those who did not. Thus, it seems reasonable to conclude that when the necessary prerequisite skills at proportional reasoning and algebra are ensured, transformational reasoning becomes a crucial ingredient to learning to solve target problems.

In spite of the limited success of this experiment, we regard these results to be the first indication that students can indeed acquire the underlying skills involved in the target problems. Although previous studies (Rosnick & Clement, 1980, Wollman, 1983) had succeeded in causing students to produce correct equations, it is not at all clear that they were correcting the students' underlying misconceptions. They may well have been solving the equations by learning simple rote strategies. For example, Rosnick and Clement found evidence for the following strategy: "convert the problem statement into a (reversed) equation (the syntactic translation strategy) and then reverse the resulting equation." While this and other such strategies may work to ensure success on this specific kind of problem, they do not correct the underlying misunderstanding. Our training study was designed to teach the underlying skills that cause the misconception. Furthermore, since our training did not involve target problems per se, we can be certain that the learning we found was of a generalizable sort.

Conclusions

The research concerning the nature of the difficult word problems exemplified by the students-professors problem has yielded two contributions of note. First, it helps to specify the nature of misconceptions. This problem exemplifies the common argument that the term misconception is a misnomer. The tendency to translate "6 students" to "6S" is actually a naive theory that students have legitimately developed through their previous experience in both the natural quantitative world and in mathematics, which they then generalize inappropriately to a new situation. Other examples in physics have been demonstrated by Clement (1982) and others. This is indeed the usual way that learning proceeds. Learning psychologists described the process early in this century when they characterized learning as proceeding by the twin processes of generalization and discrimination. When we generalize inappropriately we are not rewarded and thereby learn to discriminate the inappropriate (nonrewarded) from the appropriate (rewarded) stimulus situation. Where the learning account fails is that nonreward often does not provide adequate feedback for discriminative learning to occur. Rather it appears that the inappropriate response will drop out only after a second conceptual structure--one that leads to a correct response--is acquired. In our problem the second conceptual structure is algebra. Understanding of the algebraic symbol system permits students first to tell the difference between a pseudoequation and a true equation (e.g., by attempting to set the two sides equal) and then to differentiate the situations in which language-based pseudoequations are appropriate (e.g., 3F = 1Y for feet-yards equivalence) from those that require true equations. In most of our math education these differential situations are kept quite separate, but in target problems they are put into direct conflict. Whether students detect the conflict and respond appropriately depends on the familiarity of the competing pseudoequation and on the strength of the students' understanding of the basic algebraic symbol system.

The second contribution of this research is that it demonstrates that the target problem is one of a larger, more general difficulty of mapping from one context to another. The target problems represent one example of such a transformation, one that shares variance with problems involving transformations to and from graphs and other visual diagrams. Although we have focused in our research on algebra, our transformational factor broadens the area of application. Instructors in physics, psychology, and statistics, among others, often find that their students stumble in their grasp of a concept whenever that concept is expressed graphically. Many of us find ourselves having first to try to teach *how* graphs represent before we can teach *what* they represent. Examination of the individual problems of the transformational factor indicates that the crucial aspect is not in the conflict situation that is characteristic of target problems. Some of the problems do not have a superficially obvious incorrect solution to pull the students; yet students still have difficulty generating the correct transformation. Thus, although the salience of the conflicting incorrect solution (direct one-to-one mapping) may influence whether the problem is solved, the crux of the problem lies in understanding the semantic and syntactic rules of the abstract mathematical representational system (algebra or graphs) and how they differ from those of other representational systems. To overcome such difficulties, we believe that students must have both more explicit training in the rules of the representation system (e.g., a literal always stands for the elements of a set of numbers) and explicit experience transforming among representational systems and thereby learning the correspondences and noncorrespondences among such systems. Finally, students need help in developing monitoring strategies that provide means by which they can test for algebraic validity. Such tests included number substitution into the putative equation, for example (Wollman, 1983). Of course, this requires that the students have a correct understanding of the algebraic substitution process (Kaput, 1982).

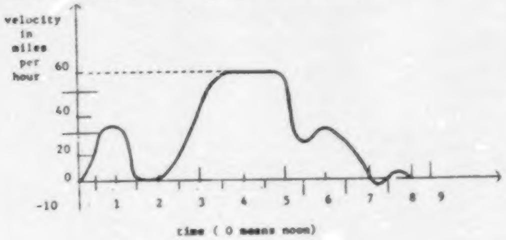
Table 1

Examples of Problems with Primary Loadings on the Two Factors of Study 2

Factor 1

Type 1. Interpreting graphs or diagrams quantitatively or nonquantitatively (6 problems)

The following graph gives the velocity of a freight train between 2 cities in terms of time elapsed on the trip from 12 noon to 8 p.m.



a. When did the train first achieve maximum velocity?________________

b. How far did the train travel between 3:30 and 4:30?________________

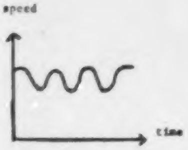
c. Explain what the train did between 7:00 and 7:30?________________

d. How far did the train travel between 1:30 and 2:00?________________

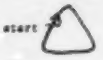
e. The train made a sudden slowdown - when did it happen?________________

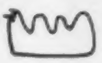
f. When did the train arrive at its destination and begin to unload?______

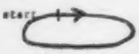
At the right is a graph which represents the speed of a racecar as it travels a single complete track route.



Below are three possible layouts for the route taken by car. Circle the most likely route taken.

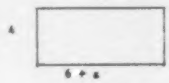
i). start 

ii) start 

iii) start 

Type 2. Interpreting graphs or diagrams algebraically (4 problems)

What is the area of the following rectangle?

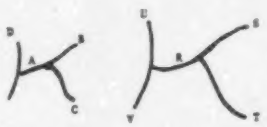


Ans:__________

Type 3. Translation between "natural" and algebraic representations (3 problems, of which two load on both factors).

Books cost b dollars apiece and records cost r dollars apiece. Suppose I buy 4 books and 3 records. What does 4b + 3r stand for?

Type 4. Proportional problems involving nonalgebraic transformations. (1 problem in main sample; 3 problems in subsamples).



These two letters are the same shape but are different in size. AC is 8 units, RT is 12 units. Curve AB is 9 units. How long is curve RS?

(a) 12 units (b) 13 units (c) 13 1/2 units (d) 15 units

Factor II

Type 1. Target problem variant: Interpretation of equation

At Vallapart Motors the equation

$$5B = 4R$$

describes the relationship which exists between B, the number of blue cars produced and R, the number of red cars produced.

Next to each of the following statements place a T if the statement follows from the equation, an F if the statement contradicts the equation, and a U if there is no certain connection.

_____a) There are 5 blue cars produced for every 4 red cars.

_____b) The ratio of red to blue cars is five to four.

_____c) More blue cars are produced than red cars.

_____d) The same number of blue and red cars are produced but the blue cars are bigger.

_____e) 5B is larger than 4R.

_____f) The equation $\frac{B}{R} = \frac{4}{5}$ expresses the same relationship between the number of blue cars and the number of red cars as the original equation below.

Type 2. Target Problems

A service station owner has found that for every 1 gallon of leaded gas he sells, he sells 3 gallons of unleaded gas. Let L stand for the number of gallons of leaded gas and U stand for the number of gallons of unleaded gas he sells. Write an equation relating the number of gallons of leaded gas to the number of gallons of unleaded gas he sells.

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